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THE MENACE OF WATER EROSION IN THE PEACE[1]

W. D. ALBRIGHT[2]

Dominion Experimental Station, Beaverlodge, Alta.

Though the black cloud of soil drifting has reappeared this year in the Peace River country, water erosion has been much the more general evil to date and may still in the long run prove the more difficult to control. Nor is it confined to the Peace. I am convinced that an unrecognized degree of damage occurs in many other parts of the West. Neatby and McCalla take cognizance of it in a forthcoming bulletin whose manuscript I have had the privilege of reading. "Soil losses due to wind and water erosion," they say, "are becoming increasingly apparent and will continue to do so unless a carefully planned system of cropping is adopted . . . . . As soon as rills or gullies begin to appear on the hillsides immediate action should be taken." Fortunately, the measures designed to prevent water erosion fit in to a large extent with those required to prevent soil drifting.

The agricultural part of the plateau flanking the Upper Peace has a ruling elevation of from 1800 to 2500 feet. After leaving the Rockies the river which drains it ploughs through a tableland with a trough canyon 600 to 800 feet deep, reducing as the plateau level declines northeastwardly against the tilt of its underlying bedrock. The Pine, the Beatton, the Smoky, and other large tributaries have similar canyons, while mere rivulets carve gaping gorges in steep descent to the trunk streams.

Save for these tributary gorges, the troughs of the larger streams drop from remarkably even rims, the plateau surface sloping gently backward from these rims to bordering uplands and these to wooded hills. The river flats are of insignificant proportion. Most of the agricultural area included within the 74,000,000-acre drainage basin of the Peace is plateau land and some of the choicest of this is that flanking the river canyons, for the rivers flow along what had probably been the silt-bottomed lobes of post-glacial lakes extending from the retreating Keewatin ice front back towards the Cordilleran range.

More remote from the canyons are certain park areas of which the Grande Prairie is the largest. There the surface is generally undulating, as the result probably of glaciation and subsequent erosion.

Nature has clothed the poorer-soiled uplands with forest, and the remaining areas with grass, coppice and bluffs, but where running water gets below the roots of the covering vegetation the birth of a chasm takes place. The gutter of to-day is the gulch of tomorrow and the gorge of

[1] Presented before a meeting of the Soils Group, C.S.T.A., at Ottawa, Ontario, June 27–30, 1938.
[2] Superintendent.

the years to come. Striking features of Peace River landscapes are the yawning canyons through which meandering rivulets descend in five, ten or twenty miles to meet the level of the streams they feed. The deep-bedded structure of shales and sandstones is undoubtedly an important explanation of this phenomenon but can hardly be the only one in a country that is geologically young, if age be reckoned from the last glaciation.

Before speculating upon other factors it may be well to record what has been observed in 30 years of agriculture on the plateau.

THE MENACE THAT MAN INTRODUCES

The menace of water erosion first came prominently to the settlers' attention in 1917 when a foot of slushy snow fell in the middle of May and disappeared during a rapid thaw. Gashes a foot deep were cut down many a sloping field. Gutters were filled in by subsequent tillage operations but washes occurring in subsequent years rescoured and deepened these, besides forming many new ditches, until thousands of fields have been lined with rock-strewn, gray depressions where crops grow poorly, where implements are passed across with difficulty and where in some cases neither teams nor tractors can cross at all.

Last month the author photographed a crooked 6-foot gash with fingered tributaries besides one or two outlying channels, all gouged through what had been a smooth field of dark soil, with probably not over a 3% fall but with a muskeg source that must have accumulated drainage from quite an area. These nasty gashes dated from a heavy downpour in July, 1935. Once the main channel was formed, lateral drainage cut the fingers leading into it. Within half a mile of this area are at least half a dozen bad washes of a similar nature.

Even on very slight slopes, roadside ditches, concentrating the run-off from several sections of land, gouge quickly into dangerous gulches, calling for riprapping at numerous culverts, cutting dangerously into the grades of the highway in places and promising jobs for drainage engineers in the years to come. Even prairie trails worn down below the grass roots develop sometimes into annoying little gulches.

Checked in the virgin state by Nature's cover of grass and trees, erosion speeds up rapidly when Man introduces the breaking plough and follows with the road grader, which concentrates excessive run-off into new channels that erode before their bottoms can be grassed or treed. When roadside ditches 10 feet deep and as wide or wider can be scored through gently sloping country in as many years, what network of ravines and chasms may 100 or 1000 years produce? No state that regards its future can afford to shut its eyes to such a menace.

Less arresting but nevertheless important is the gradual effect of sheet erosion. Every muddy trickle of water carries its quota of silt, thus thinning down the furrow slice of top soil and letting the plough dip deeper into the podsolized grey horizon. In a region where the top soil does not average more than 5 or 6 inches this cumulative loss is serious. Where gutters are cut through fields the dark loam of adjacent areas is worked in to fill these and is, in turn, washed away by succeeding freshets. Thus grey streaks appear across the cultivated fields and progressively widen.

It would not be surprising to find that some of the older fields of the Peace River country have already, in less than a generation, lost 30% of their top soil by water erosion, to say nothing of the effect upon contour nor of the inconvenient mess of rock and gravel left exposed as the soil is carried away. The Missouri Agricultural Experiment Station, catching the run-off and wash-off from a 3.68% slope, found that an average of 41.2 tons of soil per annum were removed from an acre ploughed 4 inches deep. That amount would make quite a showing if piled up by wind. Spirited away by water it is lost to sight and underestimated or ignored.

WHAT SPECIAL FACTORS MAY BE INVOLVED?

It has been already suggested that there may be other factors than contour and precipitation accounting for the observed propensity of Peace River soils to erode. In casting about for these the author is clearly on speculative ground, offering thoughts merely in the hope of provoking inquiry.

May not soil type have something to do with it? In the Peace and in other portions of the Prairie Provinces the soil either verges toward or actually represents the woodland type. Such soils after the surface layer of loam or leaf mould has been reduced lack fibre and lime in their upper horizons. They puddle into a soupy condition when wet and bake hard when dry. Their subsoil is usually compact and does not absorb moisture readily, hence is quite often dry. Thus though the annual precipitation is only 17 inches (at Beaverlodge) the run-off is rather high.

Irrigationists find that a trickle of water coursing down a slope over dry ground will soon commence cutting a channel, whereas if the soil be first judiciously moistened the same flow will be absorbed. The irregular occurrence of the precipitation in the Peace and the character of the soil both tend to keep the ground dry. Here, then, may be two factors accounting for the pronounced tendency to water erosion. Periods of very dry weather may also tend indirectly to this same end by retarding the encroachment of protective vegetation. It has been observed by the author's assistant, Mr. E. C. Stacey, that during the spring break-up after the water has worn through the frost crust the channel has deepened rapidly.

Apart from these physical factors, it may be possible that base exchange has introduced chemical factors that bear upon the matter, a possibility which might be investigated by specialists in that field.

CULTURAL CONTROL MEASURES

Since Man's practices have accelerated the process of erosion, Nature offers the first hints toward control. Nature carpets the open country with grass and over-runs as much of it as possible with forest. The draws are lined with willow scrub, whose roots lace the runways. Eroded uplands incline decidedly to trees, whose debris becomes a blotter to absorb moisture, thus inducing percolation. The ultimate northern forest-floor condition seems to be a blanket of moss peat one or more feet deep. Water is impounded in muskegs, ponds, lakes, and in backwaters where old river channels have been abandoned. Such conditions make for maximum absorption, minimum volume of run-off, a well regulated rate of run-off

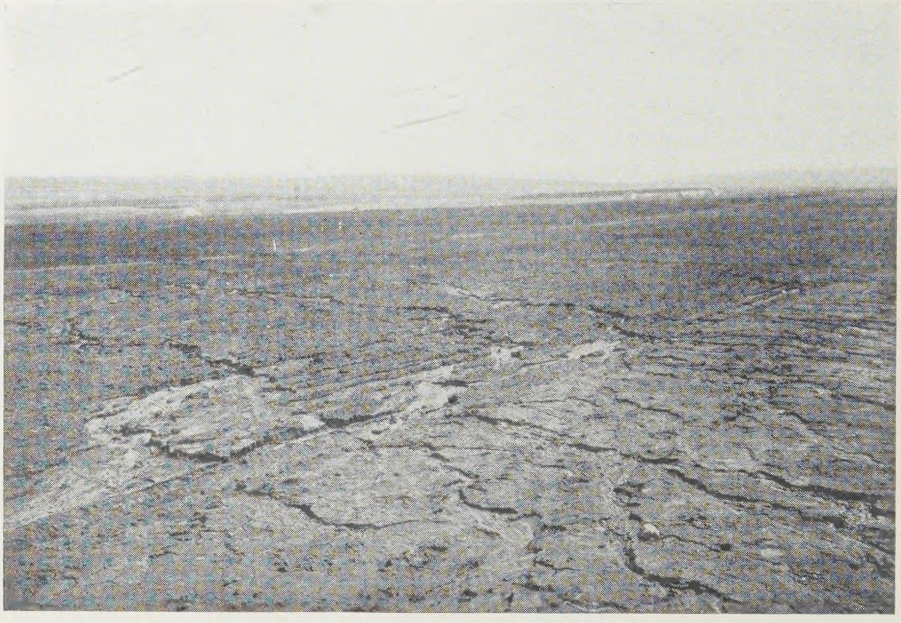

FIGURE 1. Guttering effect of spring erosion on bare cultivated ground—Beaverlodge Experimental Substation. Photograph May 7, 1932, by the author.

FIGURE 2. Six-foot gulley, with tributaries, cut through what had been a smooth field of black soil on a farm southwest of Halcourt, Alta. The havoc dates practically from the summer flood of 1935. Photograph May 27, 1938, by the author.

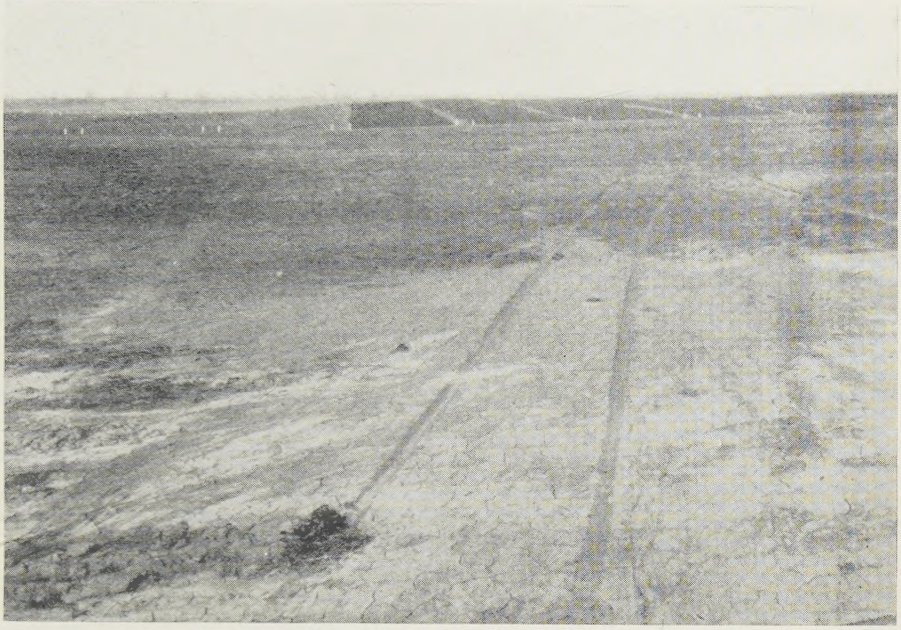

FIGURE 3. Surface loam carried by irregular gutters down a slope of fall-ploughed land (Beaverlodge Experimental Substation) and deposited in a hollow where evaporation left a slight encrustation of mineral compounds. Photograph April 29, 1931, by the author.

FIGURE 4. Brome-sodded wash across Beaverlodge Experimental Substation. Has carried three winters' run-off without scouring. Photograph May 28, by the author.

and the maximum degree of protection from the erosive action of what water does flow. Clearing, drainage and cultivation upset all this.

An illustrated folder of the United States Soil Conservation Service states that an acre of land planted continuously to corn on an 8% slope has been known to lose 61 tons of soil in a year, whereas it would require 375,000 years to lose 7 inches of top soil on a 10% slope covered by virgin forest, and more than 50 centuries to erode all the soil from a good meadow on an average slope. Nature, says the folder, builds soil faster than that.

The first need, then, is for a mapping of the country and its development along broad, far-seeing lines of conservation policy that will assure the preservation of forest where forest should grow and of grass cover on steep slopes where meadow rather than grain is the safe crop. Unless this be done the beautiful plains of the Peace will be fissured.

On the agricultural areas remaining, the same principles apply. The land should be kept clothed as much as possible. The less bare fallow one can get along with the better. Meadow is the great soil saviour. Fields under grass erode very little. Fields ploughed out of meadow resist erosion fairly well so long as the turf remains. The author has seen this repeatedly demonstrated on a farm in his charge, which has more than a 100-foot fall to the half mile. Not only does a turfy furrow impede erosion but the humus contributed by the decay of meadow residue improves the physical condition of the ground and may be reasonably expected to increase percolation. In some slight degree it restores Nature's blotter.

Cereal stubble *in situ*, while much less effective than sod, is of great help in slowing up a flow of water, spreading it out fanwise and causing it to deposit its load of silt. At the Beaverlodge Substation we have observed this time and again. Fields cultivated so as to mix the stubble with the surface soil are less prone to wash than ploughed fields. Both wind and water erosion contra-indicate autumn ploughing or the ploughing of fallow at any time, unless certain types of perennial weeds or certain insect pests necessitate it. The broad-share cultivator and the rod or the wire weeder may well substitute to a large extent for the plough, the disk harrow and the drag harrow. The tiller combine may function to advantage in a system of farming that leaves the stubble cover for dormant-season protection. C. S. Noble is experimenting with a blade weeder designed to leave the stubble as nearly as possible in its natural position. Though intended for the control of soil drifting it may also fit into a campaign against water erosion.

Contour cultivation is of some help, especially when carefully done at the last operation in the autumn, but too much must not be expected of this. With the basin lister the author has had no experience.

On the rather steep slopes of the Beaverlodge Substation it has been found inadvisable to have too broad a band under the plough or even under the cultivator. A modification of strip farming has accordingly been adopted, providing bands of intervening meadow or stubble. In one case the steeper part of a hillside field has been seeded to a permanent meadow of brome and alfalfa. If the stand needs renewing it will be broken only one-half at a time and promptly reseeded or allowed to renew itself. The hay gives a moderate annual return at a trifling cost. The hillside is not

washing any more, and the gentle slope below it is suffering much less from running water than it used to do when the whole slope was under the plough.

On the experimental grounds, sod roadways along the slope have been of decided advantage in spreading water and blocking the channels, which tend to deepen if they descend without interruption. Where intercultivated crops are grown care is taken to avoid having the rows run up and down the sharper slopes.

REPAIRING INCIPIENT DAMAGE

So much for general culture and cropping practices. The next step is in the direction of repairing damage.

Ten years ago the author took charge of a quarter section on which an irregular gash half deep enough to hide a horse had been scoured out about 5 rods from a line fence. The field was in brome, but the brome, having been seeded with a nurse crop, made a poor, thin stand and the gutter opened before a good sod was established. Once the water went below the brome roots the brome might as well not have been there. Since several rods of headland would be lost and a straight ditch along the line fence was preferred to a crooked one farther out, a furrow was ploughed in the native sod along the line fence, and the irregular gash filled with brush and straw, which was covered with the dirt thus scraped out of the new ditch. The water was directed into the straight ditch by oblique furrows well banked where they crossed the natural draw. The whole area was seeded to brome, timothy and alfalfa. Attention was paid to the lead ditches each spring but the area has become well grassed and serves as a wide headland, on which a little hay is cut each year. Now that the natural runway is sodded, we propose to let the water follow its natural course.

In another instance a natural flow was creating annual havoc by a wash diagonalling southeastward. A broad, shallow watercourse running due east was scraped out and seeded to brome, which has for two years carried the wash without signs of cutting. Implements can readily cross it and no angling edges interfere with cultivation.

On the Pouce Coupe Illustration Station several such runways have been shaped out and seeded, one to Kentucky blue and alfalfa, the others to Crested wheatgrass and alfalfa. Last spring they were functioning very well indeed.

On the Fairview Illustration Station a washing area was Mangum-terraced and is to be seeded to experimental bands of several grasses. Mangum terraces, or a near approach to them, are also being tried on the Beaverlodge Substation. Brome, Kentucky blue and Crested wheatgrass, any or all, combine well with alfalfa for this purpose. Creeping red fescue may be as good for all we know. As a general-utility crop the author prefers brome and alfalfa. The important point is to have the runways well sodded before the water is directed into them. They should be broad so as to spread the water somewhat. Narrow runways concentrate the water dangerously and are awkward to cross with implements. In some cases within our observations it has been helpful to strew or dam eroding runways in the autumn with manure but this must be regarded as a temporary expedient. It is generally advised to use woven wire to hold the debris in place but we have not yet resorted to this practice.

It has also been helpful in some cases to plough shallow furrows in the spring so as to divert water from natural draws to dry knolls or ridges under meadow crops. On two occasions the season's production of alfalfa on dry knolls has been thus increased by 500%. On cultivated ground much attention is needed to keep the water from finding its way back to the natural draws.

Where other precautions fall short we may utilize trees and scrub to lace dangerous draws with a fret work of willow and other roots. Little as a farmer may like to see tree belts cutting up his fields, is it not better to have such, with appropriate driveways at intervals through which an implement may be passed, than to have ever-deepening gulches that nothing can cross? A ditch in time may save nine times nine.

Of engineering measures the author is not competent to speak. He has confined himself chiefly to personal experience. He would suggest, however, that everything possible be learned from the experience of the United States Soil Conservation Service and that our own agricultural engineers address themselves earnestly to the problem.

CONCLUSION

The menace of water erosion is imminent and great. It is not confined to the Peace River district, although conspicuously in evidence there. Prevention is all-important, and timeliness in control measures is a duty of the State. An extensive and intensive study of the problem at home and abroad is in order and might well be entrusted to some one man who could concentrate upon it. Along with soil-drifting, this problem might well be featured under the Prairie Farms Rehabilitation Programme. If it is not studied, some fine farming country will head for ruin; production will decline; operating costs will rise, and there will be washed-out farmers to rehabilitate in the next generation. How about rehabilitating them before they reach the point of desperate need?

COMPARATIVE STUDY OF SOIL DRIFTING IN THE FIELD AND IN A WIND TUNNEL[1]

W. S. CHEPIL[2] AND R. A. MILNE[3]

Soil Research Laboratory, Dominion Experimental Station, Swift Current, Sask.

Soil drifting is a problem that has confronted the agriculturist of the open plains for many years. It occurred in certain areas of the Canadian prairie soon after the land was put under cultivation. This condition has gradually become more serious until practically all areas are more or less subject to wind erosion.

One of the main problems undertaken at the Soil Research Laboratory, Swift Current, Saskatchewan, is a study of the factors pertaining to soil drifting. Since many aspects of this problem cannot be investigated solely from field experiments, two wind tunnels were constructed in which the conditions of the wind, such as velocity, temperature, relative humidity and turbulence, can be controlled. Equipped with wind tunnels, the studies on soil drifting can be continued uninterruptedly even during years when soil drifting is not experienced.

The present paper is a report of the studies conducted for the purpose of comparing soil drifting as it occurs in the open field and in a wind tunnel.

DESCRIPTION OF WIND TUNNELS

Two wind tunnels were constructed, one for use in the laboratory and the other, a portable machine, for use in the field.

The laboratory tunnel was designed in accordance with suggestions received from the Aeronautical Branch of the National Research Council of Canada. The tunnel is of the return flow type with a test chamber 6 feet long, $2\frac{1}{2}$ feet wide and 2 feet high. A longer test chamber would be an advantage. The air blast is developed by a 3-foot propeller driven by a variable speed motor giving wind velocities up to 35 miles per hour. The velocity in any portion of the test chamber is determined by the use of a pitot tube. A greater control of velocity and more uniform test conditions can be obtained with this tunnel than with the portable machine.

The portable wind machine consists of a 5-foot propeller mounted on the rear of a car chassis and driven by a gasoline motor. The propeller is placed in front of a tunnel 4 feet wide and $3\frac{1}{2}$ feet high. The tunnel now in use is 28 feet long, but this can be increased or decreased to suit the field conditions. Wind velocities up to 35 miles per hour can be obtained. The air stream is subject to some fluctuations in velocity owing to variations in velocity of the natural wind. However, more uniform velocities are obtained than under open field conditions.

THE NATURE OF MOVEMENT OF SOIL MATERIAL IN THE WIND TUNNEL AND IN THE OPEN FIELD

Wind erosion as a geologic factor in the formation of soils has for many years been given considerable study. However, the study of erosion,

[1] Presented at a meeting of the Soils Group, C.S.T.A., held in Ottawa, Ontario, June 27–30, 1938.
[2] Soil Specialist.
[3] Graduate Assistant.

produced as a result of man's tillage of the soil, which is often spoken of as accelerated erosion or soil drifting, has, until recently, been given but little attention. Little information is available at the present time on the nature and the fundamental factors influencing drifting of arable soils.

Udden (6) concluded that lifting of soil into the atmosphere is largely due to eddies produced by wind striking surface obstructions. King (5), on the other hand, attributed much drifting of soil to internal frictional eddies produced by heated fallow surfaces.

Recent studies by Bagnold (1, 2, 3) on the movement of sand by wind in a wind tunnel give further information on the nature of drifting sand, which is apparently similar to the drifting of cultivated soil. Bagnold found that three types of movement of sand took place.

(a) Very fine particles carried in true suspension.

(b) Particles moving down wind by a series of bounces, or saltation.

(c) Surface creep, particles pushed or shoved along the surface by the impact of the particles in saltation.

The major portion of the sand movement is by particles in saltation. After being hurled steeply into the air they gain considerable momentum from the pressure of the wind acting upon them. On striking the surface they may rebound and continue their movement in saltation, or lose most of their energy by striking other particles, causing them to rise upwards and become part of the saltation movement.

Bagnold found that surface creep accounted for about 25% of the total sand movement and that it was made up of particles being rolled along the surface. He observed that there was a constant interchange of particles between saltation and surface creep.

For further analysis of the nature of movement of soil particles by the wind, theoretical calculations were made of the velocity of wind required to transport the various sized particles of soil material. The formula used in these calculations was that derived from the law of freely falling bodies, in which the velocity of the wind and the force which it produces on striking an object is expressed by $V=\sqrt{2gf}$, where V is the velocity of the wind, g the gravity constant and f the force of the wind on striking an object. Calculations show that to move a cube of medium sand of 0.5 mm. in height, a wind velocity of 10.4 m.p.h. is required.

Measurement of velocity at the surface of the ground at the time when these particles are moving freely either in a wind tunnel or in the open field, shows that this is much lower than the calculated velocity. It must be inferred, therefore, that forces other than the actual impact of the wind against the soil particles are responsible for this movement. Observations showed that soil drifting, which included the movement of particles up to 0.8 mm. in diameter, generally started when the wind reached a velocity of 13 to 15 miles per hour at 1 foot of height. This observation was found to be true both in the open field and in the 28-foot portable field tunnel but not in the laboratory tunnel of much smaller dimensions. In a typical wind gradient over a smooth fallow surface the velocity of wind required to start the movement of soil material was approximately 5 m.p.h. at $\frac{1}{4}$ inch of height, 9 m.p.h. at 2 inches, 11.5 m.p.h. at 6 inches, 14 m.p.h. at 12 inches and 25 to 30 m.p.h. at 50 feet.

For a given wind force over a similar type of surface the above variation of velocity to 12 inches in height was found to be the same in both of the wind tunnels and in the open field. More detailed discussion of the velocity gradient under the two sets of conditions will be given in the latter part of this paper. The point to note here is that the velocity required to move medium sand was not reached until about 3 or 4 inches above the ground surface. It must be concluded, therefore, that much of the momentum of these particles is derived from the relatively fast moving air some distance above the surface of the ground. This conclusion agrees with the work of Bagnold (2), who found that sand particles rose almost vertically into the air and were then driven forward by the force of the wind.

Bagnold observed that sand particles in saltation movement rose into the fast moving upper current of air for two reasons. Firstly, a particle lying motionless on the surface of the ground may be hurled steeply into the air as a result of the impact received from another fast moving descending particle. Secondly, a particle in saltation may, on striking the surface, rebound into the air and continue its movement. No explanation was given as to how soil particles rise upward into the fast moving air to contribute to the initial flow of particles in saltation. It is definitely recognized, however, that the air is made up of many momentary currents or eddies blowing in all directions with extremely variable velocities, and that the common methods of measurement denote only the average velocity and direction. These eddies, irrespective as to whether they are a characteristic behaviour of the moving turbulent air or are produced by the interferences of the ground obstacles, may enable the wind to lift a certain quantity of soil particles into the air to form the initial stage of the saltation movement.

Observations made in the laboratory wind tunnel under suitable light conditions showed that most of the movement was not produced directly by eddies caused by friction over the ground surface. Only very seldom was a particle seen to be lifted bodily by the direct force of wind. In general, the rise was either due to falling particles in saltation rebounding off the surface of the ground, or to falling particles kicking up those lying on the surface of the ground. The movement of soil by wind in a wind tunnel was observed to be largely due to the direct forward velocity of the wind rather than to the frictional eddies produced by the surface of the ground. The same must also apply to conditions in the open field since it was found that over similar ground surfaces the velocity gradient of the surface wind and the velocity of the wind required to initiate movement of the soil material were the same. The degree of eddying of the surface wind must have been the same, since, according to the accepted aerodynamic theory (4), this is entirely determined by the nature, and probably the temperature differences, of the surface.

The heights reached by particles in saltation and the relative amounts of soil moved at different heights under field conditions and in the tunnel were determined by placing soil collectors at various heights. Some of the very fine particles which were carried in suspension were not retained by the collectors, but these constituted only a relatively small proportion of the total amount of drifting soil.

The results of determinations made in the open field over loam soil showed that 57% of the total quantity of flow was between 0 to 2 inches above the ground, 18.5% from 2 to 4 inches, 8% from 4 to 6 inches, and about 16% from 6 to 38 inches. Only a small trace of soil was caught at the 38-inch height. This showed that about 93% of the total soil movement was below the height of 12 inches. Figure 1 (curve *(a)*) indicates the results obtained in the open field. Similar determinations made on other classes of soil showed no appreciable difference in the height to which the soil was carried in saltation. The data in Figure 1 were obtained during a period when the velocity of the wind varied from 15 to 22 m.p.h. at 1 foot of height. The average rate of flow between 0 to 38 inches amounted to about 570 pounds per hour per 1-foot width.

Similar results were obtained in the portable wind tunnel. Figure 2 (curves *(a)* and *(b)*) show the relative quantity of soil caught at various heights over the same soil class and the same surface as that from which

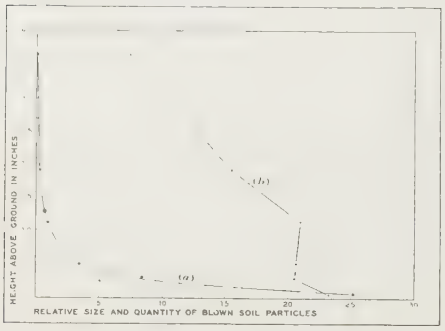

FIGURE 1. Approximate curves showing *(a)* the relative quantity of soil blown at various heights over an open summer-fallow field when wind speed ranged from 15 to 22 m.p.h. at 12-inch height, *(b)* the relative average diameter in 1/100 of a millimetre of soil particles blown during the same period.

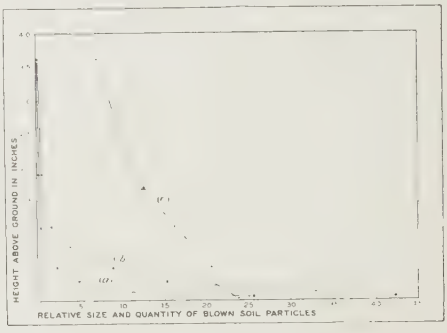

FIGURE 2. Approximate curves showing *(a)* the relative quantity of soil blown at various heights over summer-fallow in the portable field tunnel when wind speed was 18 miles per hour at 12-inch height, *(b)* the quantity of soil blown under the same conditions when the wind was increased to 25 miles per hour at 12-inch height and, *(c)* the relative average diameter in 1/100 of a millimetre of soil particles blown at both speeds of wind.

data were obtained in the open field. The rate of flow between 0 and 38-inch height amounted to about 490 pounds per hour per 1-foot width for an 18 m.p.h. wind and 995 pounds for a 25 m.p.h. wind. In the tunnel, as in the open field, about 93% of soil was carried below the height of 12 inches. The total quantities blown in the field and in the portable field tunnel for the same class of soil and velocity of wind, as far as could be ascertained, were also similar.

No definite data on the height to which soil particles were carried in saltation in the laboratory tunnel were obtained. Since the tunnel was only 2 feet high, it will at once be apparent that particles in saltation could not rise to the same heights as they did in the open field, or the portable field tunnel. Observations under a strong light indicated, however, that the general character of movement was similar, and that

particles in saltation in the laboratory tunnel often rose to 6 or more inches in height.

The average diameter of soil particles blown and the heights to which these sizes were carried in saltation, were determined by the use of sieves. The average diameter for each portion of the soil was assumed to be half way between the mesh size of the sieve which retained the soil and the next larger one. Figure 1 (curve *(b)*) indicates the average size of particles carried over loam soil in the open air. Figure 2 (curve *(c)*) on the other hand, shows the sizes of particles carried over the same class of soil at various heights in the portable field tunnel. In both cases the average size of soil particles carried was about the same. The average diameter of the particles caught at different heights ranged from about 0.07 to 0.25 mm. An increase of wind velocity from 18 to 25 m.p.h. showed no appreciable difference in the average size of particles carried.

Observations made in both wind tunnels indicated that practically no soil movement in saltation, or as surface creep, took place at the windward end of the test area, but that the amount carried was cumulative and increased with distance. The distance at which the quantity of soil carried reached the maximum was not determined definitely but it was observed to be at least 6 feet beyond the windward end of the test area.

The data obtained in the field and in the portable field tunnel indicate that soil drifting off a smooth, thoroughly dry, pulverized summer-fallow began when a wind velocity of 13 to 15 miles per hour at 1 foot of height was reached. In the laboratory wind tunnel with a 6-foot length of the exposed soil sample, definite drifting over the same type of surface did not begin until a velocity of 15 to 17.5 miles per hour was reached. It was concluded, therefore, that for the same velocity of wind the 6-foot length of the exposed sample was too short to give the same intensity of drifting as in the field, or in a longer tunnel. The relative effect of the various cultural treatments on the susceptibility of the soil to drifting showed similar trends to those observed in the field. The results of the above investigation indicated that the magnitude and character of soil movement in a wind tunnel of suitable dimensions and in the open field are similar. The tunnel, in which the magnitude of soil movement was found to be similar to that in the open field, was 28 feet long, $3\frac{1}{2}$ feet high, and 4 feet wide.

VELOCITY GRADIENT OF WIND OVER VARIOUS TYPES OF SURFACE IN THE TUNNEL AND IN THE OPEN FIELD

The drifting of soils was observed to be largely determined by the velocity gradient of the wind near the ground. As the type of surface determines the velocity gradient, a study of the relationship of these factors was considered essential.

The velocity gradient of the wind in the open and in the tunnel over similar types of surface was determined by the use of 6 pitot tubes set at definite heights. The manometers were so arranged that all 6 could be read at the same time, thus giving a record of the wind velocity at each height at any particular moment. Consecutive readings taken in the

open showed greater variations within short intervals of time than similar readings in the tunnel. This was no doubt due to the sudden changes in velocity that occur in a natural wind.

In the 28-foot portable field tunnel, no change in the velocity gradient of the wind to the height of 12 to 18 inches was observed beyond 16 feet of the windward end. The type of velocity gradient obtained beyond this distance depended entirely on the nature of the surface. In the laboratory tunnel, however, it was not possible to determine at what position the velocity gradient reached a constant value as the length of the exposed sample was only 6 feet. Yet even at this distance marked differences were obtained over various ground surfaces.

Prandtl's formula on the nature of the flow at the boundary layer was used to check the data obtained. The velocity gradients found either in the tunnel, or in the open field, as a whole fitted quite well into this formula and revealed some important facts which could not be detected otherwise. Prandtl's formula gives the velocity of the fluid near the boundary surface in terms of the magnitude of friction per unit area of surface, height of measurement above the surface and the size of the surface irregularities. This is expressed by $Vz = 5.75 \sqrt{\frac{r}{p}} \log_{10} \frac{z}{k}$ where Vz is the velocity at any height z, r is the surface friction, p the density of the fluid, and k is 1/30 of the height of surface irregularity.

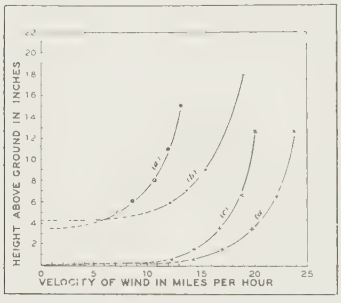

FIGURE 3. Wind velocity gradients obtained over various types of surfaces in the portable field tunnel. *(a)* Level ground surface covered with a growth of brome grass about 6 inches high, *(b)* rather thin, irregular wheat stubble about 7 inches high, *(c)* smooth, level, bare ground, *(d)* same as *(c)* with wind velocity increased.

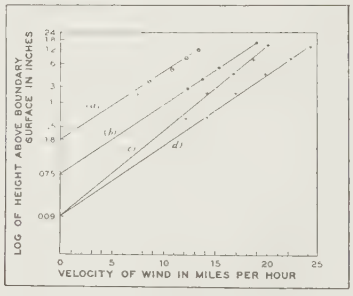

FIGURE 4. Wind velocity gradients obtained over various types of ground surfaces in the portable field tunnel. *(a)* Level ground surface covered with a growth of brome grass about 6 inches high, *(b)* rather thin, irregular wheat stubble about 7 inches high, *(c)* smooth, level, bare ground, *(d)* same as *(c)* with wind velocity increased.

Figure 3 shows some typical velocity gradients obtained over various types of surface in the portable field tunnel. By expressing the velocity at different heights by a graph in which the ordinate is the logarithm of the height, the curve of velocity becomes a straight line, as indicated in Figure 4. In Figure 4 the value of k lies at the point at which the straight line cuts the ordinate. In curves *(a)*, *(b)* and *(c)*, k is 0.18, 0.075 and 0.009 inches, respectively, which corresponds to surface irregularities of

30 times this magnitude, or, 5.4, 2.25 and 0.27 inches. These values are found to agree approximately with the actual irregularities found over the surface of the ground.

In the linear graph (Figure 3) it will be found that over certain types of surfaces, zero velocity, which indicates the position of the true boundary surface, does not fall at the actual ground surface but some distance above it, depending on the nature and size of the ground obstructions. For example, in curves *(a)* and *(b)*, zero velocity over 6-inch brome grass and 7-inch stubble falls approximately at 3.50 and 4.25 inches above the surface of the ground, respectively. The boundary surfaces, therefore, are assumed to be approximately at these levels and not at the ground surface. The values of k, irrespective of whether the data was obtained in a tunnel or in the open field, are based on these levels, which indicate approximately the irregularities of the height of the obstructions and not their actual height.

The velocity gradients obtained over various types of surface in the open field also depended entirely on the nature of the surface and the size of surface irregularities. Figure 5 indicates some of the typical velocity gradients obtained in the open field. It will be observed that the wind velocity readings at various heights above the surface of the ground on a logarithmic scale do not fall as near to a straight line as those obtained in the wind tunnel. This is due to greater inaccuracy in the readings caused by extreme variation of the velocity of the wind in the open. Nevertheless, the curves of velocity with respect to height agree approximately with those obtained over similar surface in the portable tunnel.

The wind in the laboratory tunnel, being subject to less variation in velocity, permitted the more accurate determination of the velocity gradients which were produced by the various types of surface. All determinations made at the leeward end of the 6-foot length of the exposed soil area fitted closely into Prandtl's formula. Figure 6 indicates some

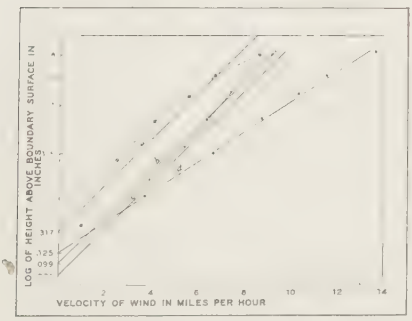

FIGURE 5. Wind velocity gradients obtained over various types of ground surface under open field conditions. *(a)* Level ground covered with a growth of stinkweed varying from 3½ to 8 inches in height. *(b)* Thick stand of brome grass about 6 inches in height. *(c)* Lister furrows, 24-inch width and 8-inch height, running at right angles to the direction of the wind. *(d)* Level ground surface covered with a short sparse growth of weeds ranging from 1 to 3 inches in height.

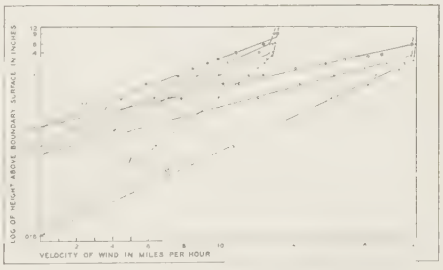

FIGURE 6. Wind velocity distribution over various types of ground surface in a laboratory wind tunnel. *(a)* Ridges 1¼ inches high, 7 inches apart running at right angles to the direction of the wind with ½ ton per acre of short straw worked into the surface. *(b)* Same at higher wind velocity. *(c)* Similar ridges without straw cover. *(d)* Smooth, level surface with ½ ton per acre of straw worked into the surface. *(e)* Same as *(d)* but under higher wind velocity. *(f)* Very smooth, bare ground surface. *(g)* Same at higher wind velocity.

typical wind gradients obtained, in which the values for the heights of surface irregularities, as determined by Prandtl's formula, are seen to correspond quite closely with the actual heights of the irregularities. It is apparent, therefore, that the velocity gradient of the wind at 6 feet within the windward edge of the test area must have reached a constant form, otherwise the values would not have fitted so well into the formula, nor would they have shown so close an indication of the size of the surface irregularities.

Analysis of the data obtained showed that the velocity gradient of the surface wind was determined by the type of surface, irrespective of whether the determinations were made in the tunnels or in the open, and that the velocity gradients produced under the two sets of conditions were similar for similar surfaces. Furthermore, an observation of the characteristic movement of the drifting soil at different wind velocities, together with the observation of vertical wind gradients led to the conclusion that soil drifting was determined more by the type of surface and force of the wind than by the turbulence of air found above the zone of the frictional eddies produced by that surface. The increase in turbulence of the upper atmosphere apparently produces an increase in the surface velocity of the wind. A similar result can be produced in the wind tunnel merely by increasing the speed of the propeller.

From the results of the investigation presented in this paper it can be concluded that the velocity gradient of the wind and the magnitude and character of soil movement in a wind tunnel of sufficient size are similar to those found in the open field.

SUMMARY

A comparative study was undertaken at the Soil Research Laboratory, Dominion Experimental Station, Swift Current, Saskatchewan, on the nature and magnitude of soil drifting in a wind tunnel and in the open field. In both the portable field tunnel and in the open most of the blown soil material was carried in saltation in which the soil particles leaped from a fraction of an inch to several feet in height. The saltation movement in the tunnel and in the open field was similar.

In the laboratory tunnel of only two feet of height the soil movement, though similar in character, was not of the same magnitude as in the open field.

The vertical velocity gradient of the wind was similar over similar types of surface, irrespective as to whether it was in the wind tunnel or in the open field. The velocity gradient of the surface wind depended entirely on the nature and size of surface irregularity. Prandtl's formula on the nature of flow near the boundary surface agreed quite well with most of the data obtained. This close agreement must imply that wind movement in a suitable tunnel and in the open field follow the same apparent aerodynamic law.

Since soil drifting was found to depend largely on the force of the wind and on the velocity gradient up to the height of about 18 inches or more, a wind tunnel of sufficient size can be accepted as a means of practically duplicating field conditions.

ACKNOWLEDGMENT

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EFFECTS OF CULTIVATION AND CROPPING ON THE CHEMICAL COMPOSITION OF SOME WESTERN CANADA PRAIRIE SOILS[1]

A. C. Caldwell,[2] F. A. Wyatt[3] and J. D. Newton[3]
Dominion Experimental Farms Service and University of Alberta

The evidence from Rothamsted and Woburn in England, and from experiments in Ohio, Missouri, Illinois and Pennsylvania in the United States, indicates a decline in yields of grain grown continuously without treatment (14).

Nitrogen analyses of various fields at Rothamsted (5, 12) show evidence of loss of this important plant food element in cultivated land.

In the United States, fertility studies have been made on soils as they exist in the field and also on soils in control experiments. An extensive review of the literature has revealed, in a large proportion of papers examined, losses of nitrogen and carbon chiefly (2, 3, 4, 6, 7, 8, 11). A few workers reported neither gain nor loss and sometimes a gain in nitrogen and carbon as a result of cultivation and cropping (10, 13).

In Canada, Shutt (9) compared virgin and cultivated soils at two locations in the West and found decreases of 25% and 30% of the original nitrogen content. Other analyses of soils cropped in a rotation led to the conclusion that the nitrogen content had been maintained and in some instances materially increased.

Farming practices employed by the farmer have been very similar over wide areas of the Western Prairies. They consist largely of a grain and fallow system claimed by many to be wasteful and extravagant in the extreme.

In any system of permanent agriculture one of the first concerns should be the maintenance of soil fertility. If soil deterioration and exhaustion are taking place evidence should be gathered as to the nature and extent of plant food losses. Decrease in fertility may be shown by decline in yields. A chemical analysis of the soil may show depletion in elements essential for plant growth. In this study an attempt has been made to determine by chemical analysis of some cropped and virgin soils what effects the present methods of farming have had on some total and easily soluble plant foods.

Soil samples were collected for this investigation from 32 widely separated points in Alberta and Saskatchewan. Duplicate samples of both cultivated soil and also of nearby virgin soil were taken at each location, and 404 samples, representing 132 profiles, were analyzed. An attempt was made to sample about the same number of locations from each of the major soil zones into which Alberta and Saskatchewan are divided.

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[2] Research Assistant, P.F.R.A., Dominion Experimental Farms.

[3] Professors of Soils, University of Alberta, Edmonton, Alta.

For the most part the samples obtained were taken in the field according to profile, but in some instances the surface horizon was divided, and in others two and part of a third were combined to make up the ploughing depth.

Total nitrogen was determined by the familiar Kjeldahl-Gunning method. Organic carbon was determined by Schollenberger's chromic acid reduction method, as modified by Allison (1). Organic matter was computed from organic carbon by multiplying by 1.724.

EXPERIMENTAL RESULTS

Nitrogen was determined on all of the 404 samples collected. Determinations of organic carbon were made on all samples of the first two depths, but time did not permit this determination for all of the lower horizons. Percentage data for nitrogen and carbon of the samples are not presented in this paper. However, it may be stated that the nitrogen content for the surface horizons of the various zones ranges within the following limits: black zone, 0.4 to 0.8%; dark brown zone, 0.2 to 0.4%; brown zone, 0.1 to 0.3%; gray wooded zone, 0.1 to 0.15%. Similarly the range in organic carbon content for the soils of the various zones is as follows: black zone, 5.0 to 10.0%; dark brown zone, 1.6 to 5.0%; brown zone, 1.0 to 4.0%; and the gray wooded zone, 2.0 to 3.0%.

TABLE 1.—LOSS OR GAIN OF NITROGEN IN CULTIVATED BLACK SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches								Total loss or gain
	0–6	6–12	12–18	18–24	24–30	30–36	36–42	42–66	
Edmonton	−2,070	+2,310	+2,659	+25	+25	+25	+25	–	+2,999
Melfort	−1,818	+1,242	+1,254	+954	–	–	–	–	+1,632
Lacombe—Rotation C	−1,044	−2,322	−1,152	+18	+18	+18	+18	+72	−4,374
Lacombe—Rotation O*	−2,268	−4,770	−1,926	+918	+918	–	–	–	−7,128
Pincher Creek	−3,222	−507	+36	+84	–	–	–	–	−3,609
Namao	−2,502	−1,359	−254	−254	−254	−254	+108	–	−4,769
Parkland	−2,952	−648	−1,041	–	–	–	–	–	−4,641
Lloydminster*	+1,486	+1,079	+522	+522	+522	–	–	–	+4,131
Vegreville	−1,582	−443	+126	+126	−222	–	–	–	−1,995
Average gain or loss	−1,775	−602	+25	+299	+168	–	–	–	–

*The analyses of samples from Lacombe (Rotation O) and Lloydminster appear to be irregular. These plots were again sampled in 1938 and when completely analyzed the additional results will be included in the final report on this work.

Nitrogen

The data in Tables 1 to 5 inclusive are calculated from the percentage figures, and contain the loss or gain of nitrogen in cultivated soils on a pounds per acre basis.

The average loss from the top 6 inches of all cultivated black soils analyzed is 1,775 pounds per acre, or 18% of the original nitrogen content. The loss from the second 6 inches is 602 pounds per acre, about 11% of the original.

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Six out of 9 cultivated fields have lost nitrogen in amounts varying from about 1 ton to $3\frac{1}{2}$ tons per acre to the depth analyzed. Three cultivated fields contained more nitrogen than the sod.

TABLE 2.—LOSS OR GAIN OF NITROGEN IN CULTIVATED DARK BROWN SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches				Total loss or gain
	0–6	6–12	12–18	18–24	
Morrin	−1,584	+108	+522	–	− 954
Edgerton	− 540	− 42	+207	+101	− 274
Cutknife	−1,692	−492	−204	−204	−2,592
Regina (E)	−2,286	−198	−198	–	−2,682
Regina (S)	−2,412	−162	−162	–	−2,736
Scott	+ 18	+ 36	–	–	+ 54
Hand Hills	− 168	+122	+245	+245	+ 444
Lethbridge—Rotation U	− 275	+ 60	+594	–	+ 379
Lethbridge—Rotation C	−1,368	+126	−198	–	−1,440
Average loss or gain	−1,145	− 47	+101	–	–

The average loss from the top 6 inches of the cultivated dark brown soil samples is 1,145 pounds, or about 22% of the original nitrogen content. The average loss of 47 pounds in the next 6 inches is a very small amount and probably not significant.

The soils of 6 out of 9 locations have been decreased in nitrogen content by cultivation, this decrease varying from 274 to 2,736 pounds of nitrogen per acre to the depth analyzed. Gains of 54 and 444 and 379 pounds of nitrogen were recorded at three locations.

TABLE 3.—LOSS OR GAIN OF NITROGEN IN CULTIVATED BROWN SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches					Total loss or gain
	0–6	6–12	12–18	18–24	24–42	
Swift Current (S)	−2,340	+171	+242	+314	–	−1,613
Gros Ventre	−1,890	−594	−594	−474	–	−3,552
Acadia Valley	+ 54	–	–	–	–	+ 54
Swift Current	+ 90	−378	−378	−342	–	−1,008
Cavendish	− 441	+234	−108	–	–	− 315
Brooks	−1,044	−414	+192	+144	+378	− 744
Cabri	− 162	− 42	− 18	–	–	− 222
Manyberries	− 387	+ 9	− 21	–	–	− 399
Average loss or gain	− 765	−145	− 98	–	–	–

The cultivated brown soils lost 20% of their nitrogen in the top 6 inches or 765 pounds per acre. The loss from 6 to 12 inches is 145 pounds or 8% of the original nitrogen content. The loss from the 12- to 18-inch depth is 98 pounds or about 8%.

Total losses of from 222 to 3,552 pounds per acre occurred at 7 out of 8 locations. The single gain was only 54 pounds per acre.

TABLE 4.—LOSS OR GAIN OF NITROGEN IN CULTIVATED GRAY TRANSITION SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches				Total loss or gain
	0–6	6–12	12–18	18–24	
Colinton	+18	−198	−276	−270	−726
Grosmont	−24	− 36	− 36	–	− 96
Average loss or gain	− 3	−117	−156	–	–

Only 2 sets of samples of gray transition soil were collected. Small losses of nitrogen occurred at both locations.

TABLE 5.—LOSS OR GAIN OF NITROGEN IN CULTIVATED GRAY SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches						Total loss or gain
	0–6	6–12	12–18	18–24	24–30	30–48	
Breton—C. 1	−1,152	−312	−144	−144	−144	−432	−2,328
Breton—C. 3	−1,098	−273	−108	−108	−108	−324	−2,019
Fallis	−1,098	−153	+ 36	+ 36	+ 36	+108	−1,035
Tweedsmuir	− 594	−129	− 36	− 36	− 36	–	− 831
MacKay—Fertilizer	+ 54	+114	+126	+126	+126	+378	+ 924
MacKay—No fertilizer	− 450	–	–	–	–	–	− 450
Average loss or gain	− 723	−151	− 25	− 25	− 25	− 68	–

The surface 6 inches of the gray soils examined lost 35% of their nitrogen on the average, as a result of cultivation and cropping. The average loss in pounds per acre to this depth is 723 pounds. The 6- to 12-inch depth lost 151 pounds or 20%.

Considering the total nitrogen gains or losses for individual locations, losses of from 450 to 2,328 pounds of nitrogen occurred in 5 instances. A gain was found at only 1 location.

Probably the most reliable figures obtained are for the surface gains or losses, since it is possible to make a better sampling of surface than of subsurface soil.

Nitrogen losses shown by the cultivated soils are, if anything, on the conservative side. Some of the heavier grass growth and roots, which would be normally turned under by a farmer, were removed from the virgin samples before they were ground for analysis.

Since most of the samples were collected from farmers' fields, it is clear that the straight grain and fallow system employed has not maintained the nitrogen content of western Canada prairie soils.

TABLE 6.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED BLACK SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches							Total organic carbon	Total organic matter
	0–6	6–12	12–18	18–24	24–30	30–36	36–42		
Edmonton	−24,840	+32,460	+37,116	+ 3,096	+ 3,096	+ 3,096	+ 6,192	+63,912	+110,184
Melfort	−24,120	+ 9,930	+11,940	+ 9,540	–	–	–	+ 7,290	+ 12,568
Lacombe—Rotation C	−11,160	−25,380	−14,220	− 3,060	− 3,060	− 3,060	− 3,060	−63,000	−108,612
Lacombe—Rotation O*	−29,340	−58,140	−23,940	+10,260	+10,260	–	–	−90,900	−156,712
Pincher Creek	−53,820	− 9,120	− 180	–	–	–	–	- 63,120	−108,819
Namao	−43,728	−23,574	− 3,126	− 3,126	− 3,126	− 3,126	–	−79,806	−137,586
Parkland	−45,540	− 9,810	–	–	–	–	–	−55,350	− 95,423
Lloydminster*	+16,896	+12,116	+ 6,120	+ 6,120	+ 6,120	–	–	+47,372	+ 81,669
Vegreville	−23,982	− 7,754	+ 360	+ 360	–	–	–	−31,016	− 53,472
Average loss or gain in carbon	−26,626	− 8,808	+ 1,760	+ 3,314	+ 2,658	–	–	–	–
Organic matter	−45,903	−15,185	+ 3,034	+ 5,713	+ 4,582	–	–	–	–

* See footnote Table 1.

Organic Carbon

The data in Tables 6 to 10 are calculated from the percentage figures and contain the loss or gain of organic carbon and organic matter on a pounds per acre basis.

The average loss of organic matter from the 0- to 6-inch depth of the black soils was 45,930 pounds, a loss of 21%. The decrease in the 6-inch to 12-inch depth was 15,185 pounds, also 21% of the original content. Six out of 9 fields show total losses varying from 31,016 to 90,900 pounds of organic carbon or 53,472 to 156,712 pounds of organic matter per acre. Gains in organic matter of 110,814, 12,568 and 81,669 pounds per acre were found at three locations.

TABLE 7.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED DARK BROWN SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches				Total organic carbon	Total organic matter
	0–6	6–12	12–18	18–24		
Morrin	−26,370	−1,710	–	–	−28,080	−48,410
Edgerton	−14,220	−5,370	− 945	–	−20,535	−35,402
Cutknife	−26,010	−6,660	−2,790	−2,790	−38,250	−65,943
Regina (E)	−31,410	−4,140	−4,140	–	−39,690	−68,426
Regina (S)	−29,790	− 360	− 360	–	−30,510	−52,599
Scott	+ 450	− 450	–	–	–	–
Hand Hills	− 2,610	− 830	–	–	− 3,440	− 5,931
Lethbridge—Rotation U	− 6,679	− 141	+4,620	–	− 2,200	− 3,793
Lethbridge—Rotation C	−18,000	+ 180	–	–	−17,820	−30,722
Average loss or gain in carbon	−17,182	−2,172	− 725	–	–	–
Organic matter	−29,622	−3,746	−1,250	–	–	–

The loss of organic matter from the surface of the dark brown cultivated soil was 29,622 pounds per acre, a decrease of 26%. The average difference between the 6-inch to 12-inch depths of sod and cultivated soils is almost 2 tons of organic matter in favour of the sod. Cultivation has apparently decreased the organic matter by 11%.

Total losses to the depth analyzed vary from 3,793 to 68,426 pounds per acre. At one location neither loss nor gain occurred.

TABLE 8.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED BROWN SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches				Total organic carbon	Total organic matter
	0-6	6–12	12–18	18–24		
Swift Current (S)	−36,990	+ 360	+1,095	+1,830	−33,705	−58,107
Gros Ventre	−31,320	−6,300	−6,300	–	−43,920	−75,718
Swift Current	+ 1,260	−5,940	−5,940	–	−10,620	−18,309
Acadia Valley	− 1,350	–	–	–	− 1,350	− 2,327
Cavendish	− 9,060	− 810	–	–	− 9,870	−17,016
Brooks	−16,470	−8,010	+ 300	–	−24,180	−41,686
Cabri	− 4,590	−1,440	− 810	–	− 6,840	−11,792
Manyberries	− 6,120	−1,080	–	–	− 7,200	−12,413
Average loss or gain in carbon	−13,080	−3,317	−2,331	–	–	–
Organic matter	−22,550	−5,719	−4,019	–	–	–

The surface 6 inches of cultivated brown soils have lost 27% of their organic matter, an average decrease of 22,550 pounds. The organic matter in the 6-inch to 12-inch depth has been lowered by 11% or 5,719 pounds per acre.

The soils at all 8 locations sampled in the brown soil zone have lost organic matter to the depth analyzed. Losses varied from 2,327 to 75,718 pounds per acre.

TABLE 9.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED GRAY TRANSITION SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches				Total organic carbon	Total organic matter
	0–6	6–12	12–18	18–24		
Colinton	+5,130	−13,410	−3,780	−3,790	−15,840	−27,308
Grosmont	−4,860	− 1,620	–	–	− 6,480	−11,172
Average loss or gain in carbon	+ 135	− 7,515	–	–	–	–
Organic matter	+ 233	−12,956	–	–	–	–

The soils at 2 locations in the gray transition zone have lost 27,308 and 11,172 pounds of organic matter per acre.

The surface 6 inches of gray soils have lost 42% of their original organic matter content, an average of 29,998 pounds per acre. Organic matter in the 6-inch to 12-inch depth has been decreased by 17% or 5,524 pounds per acre.

Total losses of organic matter ranged from 10 to 32 tons per acre at 5 out of 6 locations. One cultivated field contained nearly 6 tons more organic matter than nearby virgin sod.

TABLE 10.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED GRAY SOILS ON A POUNDS PER ACRE BASIS

Location	Depth in inches						Total organic carbon	Total organic matter
	0–6	6–12	12–18	18–24	24–30	30–48		
Breton—C 1	−24,750	−4,875	− 900	− 900	− 900	−2,700	−35,025	−60,383
Breton—C 3	−23,580	−4,980	−1,260	−1,260	−1,260	−3,780	−36,120	−62,271
Fallis	−26,460	−5,235	− 990	− 990	− 990	−2,970	−37,635	−64,883
Tweedsmuir	−11,340	−1,665	+ 270	+ 270	+ 270	–	−12,195	−21,024
MacKay—Fertilizer	− 3,240	+ 735	+1,530	+1,530	+1,530	+4,590	+ 6,675	+11,508
MacKay—No fertilizer	−15,030	–	–	–	–	–	−15,030	−25,912
Average loss or gain in carbon	−17,400	−3,204	− 270	− 270	− 270	−1,215	–	–
Organic matter	−29,998	−5,524	− 465	− 465	− 465	−2,095	–	–

A straight grain and fallow system has not maintained the organic carbon or organic matter content of western Canada prairie soils.

The C : N Ratios of Virgin and Cultivated Soils

The carbon-to-nitrogen ratios were worked out for the cultivated and virgin soils using the figures for the average percentage nitrogen and average percentage carbon of duplicate samplings.

With few exceptions the C : N ratio narrows in both virgin and cultivated soils with increase in depth. In a comparison of virgin and cultivated soils the general tendency is a narrowing of the ratio due to cultivation and cropping.

The C : N ratio of surface black soils has been narrowed from 13.4 to 12.8 as a result of cultivation and cropping. The subsurface ratios of the virgin and cultivated soils are equal, namely 11.8 : 1. The sod subsoil has an average C : N ratio of 12, and the cultivated soil 11.4.

The surface of cultivated dark brown soils has been narrowed from 12.5 to 11.7, and the subsurface from 11.4 to 10.8.

The average narrowing that has taken place in the brown soils is from 12.5 to 11.6 in the surface, and from 11.2 to 10.4 in the subsurface.

The surface of cultivated gray transition soils has a narrower C : N ratio than the virgin soil, while the subsurface cultivated has a slightly wider one.

TABLE 11.—CARBON-TO-NITROGEN RATIOS IN VARIOUS HORIZONS OF VIRGIN AND CULTIVATED SOILS FROM ALL SOIL ZONES

Location	Virgin or cultivated	Horizons		
		Surface	Subsurface	Subsoil
	Black Soils			
Edmonton	Virgin	12,2	11.3	9.4
	Cultivated	12.3	12.1	11.0
Melfort	Virgin	12.9	12.7	12.2
	Cultivated	12.9	11.8	11.5
Lacombe	Virgin	13.1	12.8	16.3
	Cultivated	13.3	13.4	11.5
	Cultivated	13.1	13.4	13.4
Pincher Creek	Virgin	13.8	11.2	
	Cultivated	12.5	11.0	
Namao	Virgin	15.0	10.5	10.0
	Cultivated	13.0	9.7	9.1
Parkland	Virgin	13.7	12.1	
	Cultivated	12.7	11.5	
Lloydminster	Virgin	13.1	12.1	12.1
	Cultivated	12.7	11.7	12.0
Vegreville	Virgin	13.3	12.0	
	Cultivated	13.0	11.2	

TABLE 11.—CARBON TO NITRATE RATIOS IN VARIOUS HORIZONS OF VIRGIN AND CULTIVATED SOILS FROM ALL SOIL ZONES—*Continued*

Location	Virgin or cultivated	Horizons		
		Surface	Subsurface	Subsoil
Dark Brown Soils				
Morrin	Virgin	11.9	10.2	
	Cultivated	10.6	9.5	
Edgerton	Virgin	12.5	11.3	
	Cultivated	10.5	9.7	
Cutknife	Virgin	13.4	12.6	
	Cultivated	12.6	13.2	
Regina (E)	Virgin	13.6	12.4	
	Cultivated	12.8	11.2	
Regina (S)	Virgin	10.8	9.3	
	Cultivated	9.6	9.7	
Scott	Virgin	12.7	12.2	
	Cultivated	12.8	11.4	
Hand Hills	Virgin	13.0	12.6	
	Cultivated	13.1	11.0	
Lethbridge	Virgin	12.6	10.8	10.0
	Cultivated	11.5	10.5	10.5
Lethbridge	Virgin	12.4	11.6	
	Cultivated	12.0	10.9	
Brown Soils				
Swift Current (S)	Virgin	13.6	12.2	12.7
	Cultivated	12.5	11.3	11.1
Gros Ventre	Virgin	13.9	11.2	
	Cultivated	12.5	11.4	
Swift Current	Virgin	13.2	11.5	
	Cultivated	13.2	10.5	
Acadia Valley	Virgin	11.7	10.1	
	Cultivated	11.0	9.7	
Cavendish	Virgin	12.6	11.0	
	Cultivated	11.1	9.3	
Brooks	Virgin	13.7	12.9	14.6
	Cultivated	12.6	11.2	12.1
Cabri	Virgin	9.5	9.4	
	Cultivated	8.2	9.0	
Manyberries	Virgin	12.1	11.4	
	Cultivated	11.3	10.7	

TABLE 11.—CARBON TO NITRATE RATIOS IN VARIOUS HORIZONS OF VIRGIN AND CULTIVATED SOILS FROM ALL SOIL ZONES—*Concluded*

Location	Virgin or cultivated	Horizons		
		Surface	Subsurface	Subsoil
Gray Transition Soils				
Colinton	Virgin	17.6	16.7	14.3
	Cultivated	15.6	17.0	14.5
Grosmont	Virgin	13.7	7.9	
	Cultivated	11.9	8.2	
Gray Soils				
Breton	Virgin	18.2	13.7	
	Cultivated	15.7	16.2	
	Cultivated	15.9	14.2	
Fallis	Virgin	19.4	16.7	
	Cultivated	16.6	13.7	
Tweedsmuir	Virgin	20.3	17.3	
	Cultivated	21.3	23.4	
MacKay	Virgin	25.2	14.8	
	Cultivated	21.8	14.4	
	Cultivated	17.7		

The C : N ratio of gray soils has been narrowed in the surface from 20.7 to 18.2 as a result of cultivation and cropping. The average C : N ratio of cultivated subsurface gray soil has apparently been widened from 15.6 to 16.4.

DISCUSSION

Soil variability is an important factor to be considered in any discussion of gains or losses of plant foods in cultivated soils. It was found in this work that duplicate soil profiles are often quite different. Some horizons were found to vary considerably in depth in duplicate profiles.

Within the horizon itself considerable variation may exist in the content of plant food elements, and if single samples only are taken, larger differences may be found between duplicate sod samples than between sod and cultivated samples. This variation can be controlled largely by composite sampling, that is, by taking many borings and lumping them together as one sample for analysis.

Most analytical methods employed in this work are quite accurate, and while there no doubt is a small personal error involved, it is apt to be much less than the possible error due to soil variability and sampling.

A necessary assumption made in this investigation is that cultivated soils when broken were similar in fertility to nearby virgin sod, which in turn has not changed in fertility. If the cultivated soil was originally more or less fertile than the virgin sod, then gains or losses would be less or greater than calculated at present.

Nitrogen

Four main agencies are thought to be responsible for nitrogen losses. They are: crop removal; leaching; erosion, both wind and water; and volatilization.

It can be calculated from the number of years of cultivation and the figures for average yields from each zone, assuming that the only crop grown has been wheat with a fallow once every 3 or 4 years, approximately how much nitrogen has been removed from the soil in crops. Thus on the average the nitrogen removal in crops from the black soils is 900 pounds, the dark brown soils 500 pounds, the brown soils 350 pounds, and the gray soils 200 pounds of nitrogen per acre.

Then the loss of nitrogen from the top foot of the black soils, due to agencies other than crop removal, is on the average about 1,500 pounds, from the dark brown soils almost 700 pounds, from the brown soils 550 pounds, and from the gray soils about 700 pounds.

Though the nitrate-supplying power of the soil is quite high, losses of nitrogen through leaching processes are not believed to take place to any extent in western Canada because of low precipitation and high evaporation in this region.

Soil drifting, when such occurs, can be a major contributing cause of nitrogen loss. A loss of 1 inch of surface soil may remove 300,000 pounds of the richest portion. A soil containing 0.2% nitrogen would lose 600 pounds of nitrogen per acre if the top inch of soil were removed by blowing. Some of the nitrogen loss found particularly in soil samples from the dark brown and brown zones may have been due to soil drifting.

Water erosion is probably a contributing factor to soil deterioration in Alberta and Saskatchewan, but it is difficult to estimate the extent of this deterioration.

No work has been done in this investigation to determine whether or not it is probable that nitrogen is lost from the soil in some volatile form. Though some workers assume that nitrogen can be volatilized from the soil, no direct experimental evidence has been produced, among the papers reviewed, that proves definitely a nitrogen loss in such a manner.

Organic Carbon

Losses of organic matter may be attributed largely to bacterial action, though soil drifting can also have a decidedly deleterious effect. An excessive loss of organic matter has occurred in many instances. The amount of organic matter required to liberate 900 pounds of nitrogen for the crops produced is about 18,000 pounds per acre. On the average 61,000 pounds of organic matter have been lost from the surface foot of cultivated black soils or about $3\frac{1}{3}$ times as much as was needed to supply 900 pounds of nitrogen per acre.

C : N Ratios

C : N ratios offer further evidence that carbon is lost from the soil at a greater rate than nitrogen. The general narrowing of the ratios in the cultivated samples indicates this. An interesting feature of the C : N ratios of the gray soils is the large proportion of C : N, about 20.1. The

organic matter contains some very coarse and woody material, not unnatural perhaps when it is remembered that it is laid down under trees and bush.

SUMMARY

Twenty-six out of 34 cultivated fields in widely scattered points in Alberta and Saskatchewan have lost nitrogen in amounts varying from 96 to 7,128 pounds per acre to the depth analyzed.

The surface 6 inches of cultivated black, dark brown, brown, and gray soils have lost on the average 1,775; 1,145; 765; and 723 pounds of nitrogen per acre respectively. This amounts to decreases of 18%, 22%, 20% and 35% of the original nitrogen content as measured by the virgin sod.

The only decrease of any magnitude that occurred in the 6-inch to 12-inch depth was in the black zone, a decrease of 602 pounds or 11% of the original nitrogen.

It was calculated that approximately one-third to one-half of the average nitrogen loss from the surface of cultivated fields in the black, dark brown, brown, and gray soils was due to crop removal.

A straight grain and fallow system has not maintained the nitrogen content of prairie soils in Western Canada.

Twenty-nine out of 34 cultivated fields examined show losses of organic matter in amounts varying from about 1 ton to over 78 tons per acre in the depth analyzed.

The surface 6 inches of cultivated black, dark brown, brown, and gray soils have apparently lost on the average 45,903; 29,622; 22,550; and 29,998 pounds of organic matter per acre respectively. These decreases amount to 21%, 26%, 27%, and 42% of the original organic matter content.

The 6-inch to 12-inch depth of the black, dark brown, brown, and gray soils have apparently lost an average of 15,185; 3,746; 5,719; and 5,524 pounds of organic matter per acre. In the same order the percentage loss was 21, 11, 11, and 17%.

A general loss or gain of organic matter at depths below 12 inches in the various zones has not been established.

A straight grain and fallow system has not maintained the organic matter content of the cultivated prairie soils of Western Canada.

Cultivation has resulted in a narrower C : N ratio in the surface horizon of 27 out of 34 cultivated fields, and in the subsurface of 22 out of 33 fields.

The C : N ratio narrows with the depth in both cultivated and virgin soils.

Gray surface soils have a C : N ratio of about 20 : 1. Other soils have a narrower ratio varying from about 10 to 13 units of carbon to 1 of nitrogen.

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CHANGES IN THE NATURE AND POSITION OF THE SOLUBLE SALTS IN CERTAIN ALBERTA SOILS AFTER TWENTY YEARS OF IRRIGATION[1]

J. B. Marshall[2] and A. E. Palmer[3]

University of Saskatchewan, Saskatoon, Sask., and Dominion Experimental Station, Lethbridge, Alta.

Some of the extensive investigations carried out for Canadian Pacific Railway Company in 1917, 1918, and 1919 on the soil from the Tilley East Irrigation Area in Alberta have already been reported (3). The present results have been combined with these for purposes of comparison and will serve to show some of the effects of twenty years of application of water to this soil.

The soil in question is of solonetz type. The surface is eroded in patches, giving a shallow pit-like micro-relief. Similar profiles have been described by Mitchell (1), and Mitchell and Riecken (2). Other characteristics, in addition to the typical surface relief, are a tough, often impermeable subsoil, with a horizon of high salt content below. The surface texture of these soils is commonly a loam, but lighter and heavier phases occur; the subsoil is usually heavier.

The fields under discussion were broken from the prairie sod about 1913 and dry farmed until 1916. They were seeded to grasses or alfalfa in 1916 and irrigated for the first time that year. Three irrigations were applied to each field in 1917; 4 to the mixed grass field and alfalfa, and 5 to the grass plots in 1918; and 3 to the mixed grass fields and alfalfa, and 4 to the grass plots in 1919. An average of 6 acre-inches per acre was used for each irrigation during this 3-year period. No record is available of the irrigation of these fields after 1919 but it is thought that it would be similar to the practice followed from 1917 to 1919.

The mixed grass field of 25 acres was used for pasture without ploughing or cultivating during the entire period of 20 years, and after the first few years Kentucky Blue Grass and White Dutch Clover superseded all other plants. The 5 acres of alfalfa and 2 acres of grass plots were broken up after 1920. There is no record of the crops grown thereafter. In 1937 these fields had covers of alfalfa and grass, respectively, so that it is possible that they were reseeded, or in the case of the grass, had gone back.

About 2,000 acres of land in the vicinity of Tilley was placed under irrigation in 1917 and since that time most of the irrigable lands have been settled. At the time the soil samples were secured in 1937, there were no important accumulations of alkali salts in the area, and crops appeared normal.

Soil samples of 1-foot sections were secured in 1917, 1918 and 1919, with a soil tube 1 inch in diameter. From 8 to 12 holes were made on each field. The dried samples from each foot section of each field were ground

[1] Presented before a meeting of the Soils Group, C.S.T.A., at Ottawa, Ontario, June 27-30, 1938.
Part of this work was done in the laboratories of the Department of Soils, University of Saskatchewan, in collaboration with the Dominion Experimental Farms, with financial assistance from the Prairie Farms Rehabilitation Act.
[2] Dominion Experimental Farms Service.
[3] Senior Assistant, Field Husbandry and Irrigation.

and mixed by rolling on canvas and a composite sample secured for analysis. Analyses were not made in those years of the soil from each individual hole.

In 1937 the samples were obtained by using a 4-inch post-hole auger with an extension shank. The soil from successive 1-foot sections was placed on a canvas tarpaulin, mixed with a trowel, and subsampled. Samples from each hole were kept and analyzed separately; 6 holes were dug in the mixed grass pasture field and 3 each in the alfalfa and pasture grass fields. Averages only are recorded in this paper as they are comparable with the earlier results. As far as possible, the same analytical methods were employed, a 1 : 10 water extract being used instead of the usual 1 : 5 ratio of soil to water.

TABLE 1.—SUMMARY OF ANALYTICAL DATA. WATER SOLUBLE SALTS FROM THE MIXED GRASS FIELD, TILLEY, ALBERTA

—	Depth, feet	1917		1918		1919		1937
		May	Sept.	May	Sept.	May	Sept.	Sept.
Total soluble salts in percent	1	0.47	0.48	0.34	0.32	0.19	0.73	0.14
	2	0.53	0.38	0.54	0.72	0.47	0.31	0.38
	3	2.37	1.29	1.40	1.85	1.14	0.99	0.91
	4	2.64	1.71	2.44	1.74	1.10	2.07	1.87
	5	2.11	1.17	1.59	1.79	1.56	1.83	1.56
	6	1.98	1.97	1.46	1.35	1.23	2.03	1.41
Calcium*	1	2.60	2.40	2.00	0.95	1.65	6.45	0.70
	2	2.80	2.60	2.20	2.00	3.55	0.05	1.90
	3	15.75	11.65	5.40	8.55	8.30	6.55	7.70
	4	22.65	16.25	11.85	7.65	7.15	15.95	18.70
	5	15.25	9.45	16.10	7.65	10.75	15.35	14.90
	6	14.35	17.95	5.40	4.85	6.75	13.30	12.55
Magnesium	1	1.40	1.40	0.98	0.58	0.74	2.14	0.49
	2	1.73	0.90	1.32	1.98	1.95	1.76	0.90
	3	10.53	3.87	3.95	5.76	4.11	1.81	2.64
	4	7.48	4.11	5.84	5.35	3.62	4.85	4.60
	5	6.33	3.79	4.68	5.18	5.18	4.85	4.86
	6	5.68	4.94	4.20	3.95	4.11	4.85	5.51
Sodium	1	–	0.41	–	0.57	–	–	0.77
	2	1.16	0.72	2.76	4.64	1.37	–	2.47
	3	5.69	1.44	8.91	10.82	3.22	1.89	0.56
	4	6.20	2.17	12.95	10.87	4.06	2.04	2.64
	5	6.67	3.08	1.35	11.20	5.60	4.16	3.61
	6	6.83	3.80	11.32	11.64	9.57	6.96	2.99
Sulphates	1	0.60	1.15	1.19	0.44	0.02	5.82	0.90
	2	3.56	1.69	4.93	7.14	5.64	0.02	4.11
	3	30.90	15.42	17.33	24.20	14.80	9.61	11.55
	4	34.66	21.20	29.84	23.20	14.22	22.27	25.16
	5	27.18	15.06	21.33	23.41	20.92	23.82	22.73
	6	25.93	25.49	20.12	21.10	19.82	24.65	20.41
Carbonate	1	3.13	3.06	1.74	1.66	1.41	0.90	0.97
	2	2.13	2.54	1.34	1.48	1.23	0.77	1.17
	3	1.07	1.54	0.93	0.93	0.84	0.64	1.35
	4	1.07	1.33	0.80	0.67	0.61	0.57	0.79
	5	1.07	1.26	0.80	0.62	0.61	0.54	0.72
	6	0.93	1.20	0.80	0.34	0.61	0.46	0.64

* Individual ions expressed in milliequivalents.

RESULTS

Summaries of the analytical data are given in Tables 1, 2 and 3 These include results from samplings in May or June, and September of 1917, 1918, and 1919. The June 1917 results are indicative of the kind and position of the salts before irrigation was begun. It is at once apparent

TABLE 2.—SUMMARY OF ANALYTICAL DATA. WATER SOLUBLE SALTS FROM THE PASTURE GRASS PLOTS, TILLEY, ALBERTA

—	Depth, feet	1917		1918		1919		1937
		June	Sept.	May	Sept.	May	Sept.	Sept.
Total soluble salts in percent	1	0.48	0.60	0.40	0.44	0.40	0.46	0.07
	2	0.28	0.73	0.47	0.84	1.85	0.68	0.60
	3	2.36	1.30	2.50	2.13	3.67	1.74	1.38
	4	2.87	2.96	2.44	2.32	2.70	2.62	1.43
	5	3.00	2.56	1.98	2.12	2.40	2.26	1.50
	6	2.45	2.13	1.66	1.75	1.83	1.74	1.38
Calcium*	1	1.30	2.50	2.10	1.25	2.40	2.05	1.20
	2	0.60	4.15	2.80	5.60	17.95	5.70	6.25
	3	22.95	10.10	17.20	16.15	36.80	14.60	18.61
	4	27.10	27.80	13.75	14.90	25.05	24.75	17.05
	5	29.20	23.60	12.05	12.60	20.80	20.20	16.95
	6	21.75	18.90	9.25	9.70	13.80	12.50	14.95
Magnesium	1	1.32	1.73	1.97	0.82	0.08	1.48	0.58
	2	0.74	2.46	2.39	2.46	4.86	2.55	1.98
	3	5.11	4.36	4.52	3.46	5.93	4.28	2.30
	4	6.01	8.06	5.10	5.10	5.93	4.69	3.54
	5	6.42	6.50	5.10	5.18	5.76	4.69	4.12
	6	5.68	5.43	4.36	4.61	4.86	4.28	4.03
Sodium	1	0.87	–	–	2.40	–	–	–
	2	2.09	1.52	–	1.76	1.44	–	0.40
	3	4.29	–	8.76	10.04	2.85	0.44	2.26
	4	4.27	1.76	12.58	11.56	3.98	3.27	0.79
	5	5.26	1.44	11.22	11.47	5.87	4.27	0.30
	6	6.15	–	10.52	9.62	5.58	4.78	1.33
Sulphates	1	0.69	0.92	0.75	4.06	1.12	0.02	0.56
	2	0.73	6.53	1.80	9.43	24.72	6.45	7.77
	3	31.00	16.54	29.35	29.44	45.15	18.86	20.39
	4	37.30	38.90	29.08	31.36	34.65	32.27	20.72
	5	40.70	33.90	27.20	29.10	32.20	28.73	20.80
	6	32.30	30.01	23.20	23.78	23.99	21.23	19.79
Bicarbonate	1	2.80	2.93	1.12	0.41	1.05	0.85	1.07
	2	2.70	1.61	1.13	0.34	0.53	0.62	0.85
	3	1.33	1.20	1.13	0.21	0.43	0.48	0.77
	4	1.07	0.80	1.35	0.20	0.31	0.44	0.66
	5	1.07	0.67	1.07	0.15	0.23	0.43	0.57
	6	1.33	0.67	0.93	0.15	0.25	0.33	0.52

* Individual ions expressed in milliequivalents.

that the greatest concentration of salts occurs below the second foot depth and that there has been a general diminution in the amount together with a gradual downward movement of the salts, although these changes have not been progressively uniform with each successive sampling. From 1919 to 1937 the removal of salts from the depths sampled has not been as great

TABLE 3.—SUMMARY OF ANALYTICAL DATA. WATER SOLUBLE SALTS FROM ALFALFA PLOTS, TILLEY, ALBERTA

	Depth, feet	1917		1918		1919		1937
		May	Sept.	May	Sept.	May	Sept.	Sept.
Total soluble salts in percent	1	0.33	0.66	0.52	0.50	0.38	0.20	0.08
	2	0.61	0.35	0.92	0.45	0.36	0.31	0.13
	3	2.81	1.51	2.02	2.57	0.71	1.22	0.31
	4	3.00	2.13	3.28	3.05	2.68	2.53	2.36
	5	2.73	3.05	2.25	2.16	2.33	2.50	1.87
	6	1.98	3.10	1.47	1.77	1.75	1.54	1.30
Calcium*	1	1.40	3.40	1.95	1.15	1.85	0.90	0.90
	2	3.40	1.20	3.45	1.15	1.90	1.40	0.50
	3	24.65	13.95	17.95	23.20	4.00	9.05	2.90
	4	24.65	19.05	35.25	30.50	24.00	22.05	23.75
	5	19.75	25.50	18.50	21.35	18.50	19.10	16.40
	6	13.45	25.40	6.90	18.25	11.05	8.25	11.30
Magnesium	1	1.15	2.80	1.64	1.15	–	0.82	–
	2	2.88	1.73	2.06	0.82	0.90	1.01	0.16
	3	8.46	5.50	7.30	6.41	2.47	4.36	2.22
	4	10.46	7.07	8.87	6.92	7.08	6.41	3.70
	5	9.45	9.95	7.15	6.17	7.15	8.46	6.66
	6	6.58	9.85	4.36	4.60	5.92	5.59	4.44
Sodium	1	5.07	–	0.93	1.34	–	–	0.86
	2	2.23	–	10.21	2.19	–	0.23	1.39
	3	–	0.52	2.54	5.03	1.83	1.46	4.15
	4	6.01	2.08	–	7.55	3.98	4.60	6.84
	5	9.00	6.62	4.59	5.59	–	5.83	4.28
	6	7.37	6.72	7.58	0.16	–	25.23	10.04
Sulphate	1	4.62	2.73	3.42	2.15	–	0.02	0.56
	2	6.51	1.15	14.70	2.90	1.50	2.08	0.79
	3	30.80	18.90	27.20	33.80	7.58	14.40	8.14
	4	40.08	27.40	42.50	44.40	34.50	32.60	33.60
	5	37.40	41.50	29.50	32.60	–	33.00	26.60
	6	26.60	41.30	18.10	22.60	–	38.70	18.10
Bicarbonate	1	3.06	1.87	1.10	1.49	1.18	0.64	1.20
	2	2.00	1.74	1.02	1.26	0.97	0.56	1.26
	3	1.07	1.07	0.59	0.84	0.72	0.48	1.13
	4	0.94	0.80	0.95	0.57	0.56	0.46	0.71
	5	0.80	0.67	0.74	0.51	0.56	0.39	0.76
	6	0.80	0.67	0.74	0.41	0.64	0.39	0.72

* Individual ions expressed in milliequivalents.

as might have been expected when compared with the change during the 1917–1919 period. However, no harmful effects from these salts have been observed, although the concentrations in the lower depths remain moderately high, and might cause deterioration of the soil, should a rise in position take place.

At the time of the earlier investigation, Palmer (3) observed an ameliorating effect of calcium sulphate on the other salts. Sodium and magnesium sulphates could be present in moderately high concentrations without causing serious harm to the crops, provided sufficient calcium sulphate was present as well. A quantitative examination of the salts has shown that they consist largely of sulphates of calcium, magnesium and sodium,

69160—3½

TABLE 4.—PROPORTION OF INDIVIDUAL CATIONS CALCULATED FROM MILLIGRAM EQUIVALENTS

Depth	May 1917			Sept. 1917			May 1918			Sept. 1918			May 1919			Sept. 1919			Sept. 1937		
	Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na
Mixed Grain Plot Samples																					
1	66.0	34.0	–	57.0	33.0	10.0	67.0	33.0	–	45.5	27.5	27.0	69.0	31.0	–	75.0	25.0	–	37.5	26.5	36.0
2	49 5	30 5	20 0	62 0	21 0	17 0	38 0	21 0	41 0	23 0	23 0	54 0	51 6	28 4	20 0	97 0	3 0		36 0	17 0	47 0
3	49 5	33 0	17 5	68 7	22 8	8 5	29 5	21 5	49 0	34 0	23 0	43 0	53 3	26 2	20 5	63 8	17 7	18 5	59 7	20 5	19 8
4	62.0	21.0	17.0	72.3	18.2	9.5	38.8	19.0	42.2	32.0	22.4	45.6	48.3	24.4	27.3	70.0	21.0	9.0	72.0	17.8	10.2
5	54 0	22 4	23 6	58 0	23 1	18 9	72 5	21 4	6 1	31 8	21 6	46 6	50 0	24 0	26 0	63 0	19 9	17 1	63 5	20 7	15 8
6	53.5	21.5	25.0	67.5	18.5	14 0	25.8	20.2	54.0	23.7	19.3	57.0	33.0	20.0	47.0	53.0	19.2	27.8	59.6	26.2	14.2
Pasture Grass Plot Samples																					
1	37.2	37.8	25.0	59.5	40.5	–	51.5	48.5	–	28.0	18.5	53.5	97.0	3.0	–	60.0	40.0	–	67.0	33.0	–
2	17.5	21.5	61.0	51.0	30.4	18.6	54.0	46.0	–	57.0	25.0	18.0	74.0	20.0	6.0	69.0	31.0	–	72.5	23.0	4.5
3	71.2	15.6	13.2	57.0	24.6	18.4	56.5	14.8	28.7	54.3	11.7	34.0	80.2	13.0	6.8	75.5	22.2	2.3	88.0	10.8	1.2
4	70 6	15 6	13 8	70 0	20.3	9 7	43 5	16 5	40 0	47 0	16.2	36 8	71 5	17 0	11 5	75 5	14 5	10 0	80 0	16 5	3 5
5	70 0	15 4	14 6	68 0	18 8	13 2	42.5	18 0	39 5	43.0	17.7	39.3	64.0	17.8	18 2	69 3	16 1	14 6	79 5	19 1	1 4
6	66.5	17 5	16 0	61 5	17 7	20 8	38.4	18 1	43.5	40 5	19.2	40 3	57.0	20 0	23 0	58 0	19 8	22 2	73 5	20 0	6 5
Alfalfa Plot Samples																					
1	18.4	15.1	66.5	55.0	45.0	–	43.0	36.4	20.6	31.6	31.6	36.8	100.0	–	–	52.5	47.5	–	51.0	–	49.0
2	40.0	33.8	26.2	41.0	59.0	–	22.0	13.0	65.0	27.6	19.6	52.8	68.0	32.0	–	53.0	38.0	9.0	24.5	8.0	67.5
3	74.5	25.5	–	70.0	27.5	2.5	64.5	26.3	9.2	67.0	18.5	14.5	48.0	30.0	22.0	60.8	29.2	10.0	31.2	24.0	44.8
4	60.0	25.5	14.5	67.5	25.5	7.0	80.0	20.0	–	67.5	15.7	16.8	68.5	20.0	11.5	66.5	19.6	13.9	69.2	10.8	20.0
5	51.7	24.7	23.6	60.6	23.7	15.7	61.2	23.6	15.2	64.5	18.6	16.9	–	–	–	57.3	25.3	17.4	60.0	24.4	15.6
6	49.0	24.0	27.0	60.5	23.5	16.0	36.6	23.0	40.4	79.4	20.0	0.6	–	–	–	21.1	14.3	64.6	44.0	17.2	38.8

with calcium sulphate predominating. Small amounts of bicarbonate ion were present, the highest concentrations occurring in the depths nearest the surface. Traces of chloride and carbonate ions were found in occasional samples only. Data on the individual ions expressed in milliequivalents are included in the summary tables.

In order to compare the relative amounts of calcium, magnesium and sodium salts[4] comprising the totals on different sampling dates, proportions in percentages were determined from the milliequivalents. This method was considered more suitable than that of calculating the conventional combinations of the various ions because it permits an expression of proportion based on the equivalent weights of the ions rather than percentages of the various salts.

Data showing the relative concentration of Ca, Mg, and Na ions are given in Table 4. There is considerable variability between the samples from the 3 fields; whether this arises from the effects of cropping or from local soil differences and sampling errors, cannot be readily determined from this data. However, an important consideration from the point of view of the desirability of a favourable ratio of calcium to magnesium and sodium salts is that the proportion of calcium ion remains high.

Some additional information on the samples taken in 1937 is contained in Table 5. Effervescence with hydrochloric acid indicates that the carbonates are generally in the second and third feet. The higher pH values also occur at these depths. In a few cases traces of titratable carbonates are recorded, but not as often as the pH determinations would indicate. These were made colorimetrically and range from 7.2 to 9.0.

Although no data are available to follow changes in nitrogen and organic matter resulting from irrigation, it is interesting to compare the nitrogen contents of these samples with analyses of similar soil from the same area reported in Bulletin 28 of the University of Alberta.

It appears from these data that the grass and alfalfa grown under irrigation have improved the nitrogen status of the soil. In addition, levelling for irrigation and subsequent cultivation have improved the blow-out pits and greatly increased the uniformity of the surface soil. An indication of the importance of alfalfa in rotations for irrigation farming may be obtained from the above data.

DISCUSSION

Land similar to that which has been considered in these investigations has been successfully producing crops under irrigation for a number of years. At the time of the last sampling the weed problem appeared to be more serious than anything associated with soil deterioration. The removal of salts has been slow during the past twenty years but there is still a favourable condition with regard to the type of salt, as calcium remains the predominating cation. The more soluble salts, such as magnesium and sodium sulphates, are most readily removed in the excess water, and where drainage is adequate there will be small tendency for accumulation. It should be borne in mind, however, that under less favourable conditions,

[4] Sodium determined by difference.

important changes with respect to the base saturation of the colloidal complexes may result eventually in an undesirable condition of the soil.

The structure of this type of soil under dry land farming is undesirable, but under irrigation it has not proved to be a serious handicap after the soil has been cropped for a few years. It is possible that, with adequate water, deeper root penetration of crops is promoted, which results in a

TABLE 5.—ADDITIONAL DATA ON INDIVIDUAL SAMPLES TAKEN IN 1937; pH VALUES AND EFFERVESCENCE WITH HYDROCHLORIC ACID

Samples		pH values at various depths in feet					
		1	2	3	4	5	6
Mixed Grass Plots	L_1	8.3	8.5	8.5	7.8	7.8	7.8
	L_2	7.8	8.8	8.6	8.0	7.6	7.6
	L_3	7.5	9.0	9.0	8.4	8.2	7.8
	L_4	7.6	8.3	8.8	7.8	7.6	7.6
	L_5	7.2	8.8	8.6	8.5	8.4	7.8
	L_6	7.5	8.5*	8.8*	7.6	7.8	7.8
Pasture Grass Plots	L_1	7.8	8.0	7.8	7.6	7.6	7.4
	L_2	7.8	8.4	7.8	7.6	7.8	7.8
	L_3	8.4	8.5	8.0	7.8	7.6	7.8
Alfalfa Plots	L_1	8.0	8.4	8.9*	8.7	8.4	8.4
	L_2	8.4	8.8*	8.6*	7.8	7.8	7.6
	L_3	7.8	8.6*	8.4	8.4	8.4	8.4
		Effervescence at various depths in feet					
Mixed grass plots	L_1	Str.	Str.	M.	Sl.	Sl.	Sl.
	L_2	Sl.	Str.	Str.	Sl.	Sl.	Sl.
	L_3	Nil.	V. str.	Str.	M.	Sl.	V. sl.
	L_4	Sl.	Str.	Str.	Sl.	V. sl.	V. sl.
	L_5	Nil.	Str.	Str.	Sl.	V. sl.	V. sl.
	L_6	Sl.	Str.	Str.	Sl.	V. sl.	Sl.
Pasture grass plots	L_1	Nil.	Str.	M.	M.	Sl.	Sl.
	L_2	Str.	Str.	Sl.	Sl.	Sl.	Sl.
	L_3	Str.	Str.	Sl.	Sl.	Sl.	Sl.
Alfalfa plots	L_1	M.	Str.	Str.	Sl.	Sl.	Sl.
	L_2	Str.	V. str.	Str.	Sl.	Sl.	Sl.
	L_3	Str.	Str.	Str.	Sl.	Sl.	Sl.

* Traces of titratable carbonates.

more favourable distribution of organic matter and concomitant redistribution of bases, arising from the decomposition of root and crop residues. Within certain limits, the organic matter status of the soil can be improved by the use of suitable rotations. When water no longer remains a limiting factor, factors of fertility should be considered.

TABLE 6.—NITROGEN PERCENTAGES IN TOP 12 INCHES OF ALBERTA BLOW-OUT SOILS

Irrigated soils		Virgin soils	
Mixed grass plots	0.157	Loam, edge of blow-out	0.116
Pasture grass plots	0.161	Loam, centre of blow-out	0.098
Alfalfa plots	0.177	Silt loam, slightly solonized	0.138
		Silt loam, centre of blow-out	0.093

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THE NITRATE AND MOISTURE CONTENT OF SOIL UNDER VARIOUS CROPS AND TREATMENTS AT SASKATOON, SASKATCHEWAN[1]

H. W. E. Larson[2] and J. Mitchell[3]
University of Saskatchewan, Saskatoon, Sask.

The rate of nitrate production and accumulation in cultivated soils is dependent on many factors, among which are the temperature and moisture of the soil, the system of cropping and cultural practices followed, and the nature of organic residues or fertilizers used. Since the processes leading up to, and producing, nitrification are biochemical, there are many factors which might influence the activities of the soil organisms concerned in decomposition and oxidation of nitrogenous compounds. A comprehensive discussion of the processes of nitrification and the conditions affecting them may be found in the well-known text book by Russell (2).

A study of the nitrate and moisture content of the soil of certain Field Husbandry plots of the University of Saskatchewan was begun in 1928. The study was continued throughout the crop seasons of 1928 to 1932, inclusive.

CLIMATE AND SOIL

The average annual precipitation at Saskatoon for the period 1904 to 1935 was 13.6 inches, about half of which occurred during the growing season. The average annual temperature is approximately 34.8° F., and the average frost-free period is about 100 days, the length of the period free from killing frosts being somewhat longer. Growth ordinarily begins in April and continues into September. April is the first month in the spring and October the last in the fall with temperatures averaging above freezing. The average monthly temperature and average monthly precipitation for April to October are shown in Table 1.

Table 1.—Average temperature and precipitation by months, April to October

—	April	May	June	July	Aug.	Sept.	Oct.
Average temperature °F.	38	57	60	65	62	51	39
Average precipitation in inches	0.65	1.40	2.79	2.36	1.72	1.49	0.83

The coincidence of moist warm weather together with long hours of daylight are favourable to biological activity and to the completion of the growth cycle in a relatively short period. Fluctuations in the amount and time of precipitation are quite extreme and fluctuations in temperatures are also considerable.

[1] Presented before a meeting of the Soils Group, C.S.T.A., at Ottawa, Ontario, June 27–30, 1938.

[2] Formerly Assistant in Soils, University of Saskatchewan; now Extension Soil Specialist, Idaho Agricultural Experiment Station, Moscow, Idaho.

[3] Professor of Soils, University of Saskatchewan.

The soil on these plots is derived from glacio-lacustrine deposits. It has been mapped in the Elstow series and described in Soil Survey Report No. 10 (3). The surface soil is a dark brown friable heavy silty clay loam to clay. The subsoil is heavier than the surface, more compact, and of a columnar structure. Free lime is usually found at a depth of 15 inches. Owing to the relatively shallow depth of the parent lacustrine material, and to a certain amount of reworking of the deposit by stream action, considerable soil variability may occur within short distances. The native fertility of the soil is comparatively high. The land has been under cultivation for some 25 years, and the rotations and treatments included in this study were established in 1922.

ROTATIONS AND TREATMENTS

Two rotations and continuous wheat were included in the study.

Rotation A is a 5-year rotation of summerfallow, wheat, corn (intertilled), oats sown to sweet clover, and sweet clover. The 5 blocks of this rotation were at this time subdivided into plots on which various fertilizer and residue treatments were being applied. Four treatments were selected for study. These treatments were $2\frac{1}{2}$ tons of straw, 12 tons of manure, 12 tons of manure plus 250 pounds of superphosphate (16%), and 250 pounds of superphosphate per acre. The manure and straw were applied during the summerfallow season and the superphosphate broadcast at seeding time of the wheat crop.

Rotation S consisted of a simple 3-year rotation of summerfallow, wheat and oats, versus continuous wheat. There were no fertilizer treatments on the latter series.

METHODS AND TIMES OF SAMPLING

Five samplings were made each season. The approximate times of sampling were the 1st of May, the middle of June, July and August, and the 1st of October. The exact dates of sampling varied slightly depending on seasonal weather conditions.

Surface samples were taken to a depth of 6 inches at 10 points in each plot. These samples were composited and a portion sufficient for the laboratory determinations stored in a Mason jar. Samples of lower depths were taken on Rotation S only, i.e., summerfallow, wheat, oats, versus continuous wheat. The samples from lower depths were obtained by the use of a soil auger and were taken at 3 points within each plot. All samples were treated with toluene in order to prevent further nitrification before the determination of nitrates had been completed.

The moisture content was determined by drying in an oven at 105° C., and moisture percentages are reported on the oven dry basis. Nitrates were determined as outlined by Harper (1).

DISCUSSION OF NITRATE AND MOISTURE DATA OF ROTATION A

As stated previously, rotation A is a 5-year rotation of summerfallow, wheat, corn, oats sown to sweet clover, and sweet clover. Table 2 gives the nitrate content of the soil under each crop throughout the growing season. In Table 3 the results have been summarized into 5-year averages.

TABLE 2.—NITRATE CONTENT OF SURFACE SOIL OF ROTATION A, 1928–32

Crop	May 1, p.p.m.	June 15, p.p.m.	July 15, p.p.m.	Aug. 15, p.p.m.	Oct. 1, p.p.m.
1928—					
Summerfallow	8.5	6.8	4.8	25.7	68.3
Wheat	21.9	9.7	3.7	2.7	7.5
Corn	9.1	16.5	9.3	7.8	9.4
Oats and Sweet Clover	11.1	6.0	3.0	1.7	4.3
Sweet Clover	10.7	13.3	4.4	1.3	4.2
1929—					
Summerfallow	10.2	7.4	17.8	36.9	38.1
Wheat	40.9	29.0	8.8	8.1	14.3
Corn	15.1	14.7	22.5	19.1	18.9
Oats and Sweet Clover	19.5	9.2	2.0	2.3	6.1
Sweet Clover	12.9	4.0	1.5	2.0	5.4
1930—					
Summerfallow	9.0	12.9	22.9	34.1	26.8
Wheat	42.9	26.7	6.7	7.6	8.8
Corn	19.7	21.5	28.6	26.5	13.9
Oats and Sweet Clover	23.1	12.1	3.9	1.3	3.2
Sweet Clover	9.5	7.8	2.9	2.9	6.3
1931—					
Summerfallow	13.4	14.2	20.1	38.1	17.6
Wheat	37.3	39.2	9.1	9.8	6.9
Corn	14.6	23.9	19.3	11.9	10.3
Oats and Sweet Clover	14.0	16.1	5.0	5.8	4.3
Sweet Clover	7.2	5.0	6.6	2.4	6.3
1932—					
Summerfallow	4.6	5.4	20.3	35.4	43.3
Wheat	16.7	20.7	4.8	6.0	11.6
Corn	12.7	18.3	25.0	24.5	13.8
Oats and Sweet Clover	12.5	7.3	1.2	3.5	2.1
Sweet Clover	5.9	1.9	1.3	5.2	3.4

TABLE 3.—AVERAGE NITRATE CONTENT OF ROTATION A

Crop	Parts per million				
	May 1	June 15	July 15	Aug. 15	Oct. 1
Summerfallow	9.1	9.2	17.8	34.0	38.8
Wheat	31.9	25.2	6.6	6.8	9.8
Corn	14.2	19.0	20.9	17.9	13.3
Oats and Sweet Clover	16.0	9.1	3.0	2.9	4.0
Sweet Clover	9.2	6.4	3.3	2.7	5.1

Similarly the moisture data are given in Tables 4 and 5 and are expressed as percentages of moisture on the oven dry basis. Figure 1 is a graphical representation of the results for the nitrate and moisture data as averages over the 5-year period.

The largest accumulation of nitrates occurs under summerfallow (Tables 2 and 3), a result which is to be expected, and which has already been obtained at the University of Alberta (4, 5) where somewhat similar climatic conditions prevail. During the 5-year period the average amount

of nitrate nitrogen was 9 parts per million at the first date of sampling, and at the last date reached an average of 38.8 p.p.m. Rapid accumulation of nitrates occurs between the middle of June and the middle of August. This coincides in general with favourable moisture and temperature conditions, as indicated in Table 1. The wheat crop following summerfallow had a relatively large supply of nitrates available at the beginning of the season. The nitrate content in the spring following the summer-

TABLE 4.—MOISTURE CONTENT OF SURFACE SOIL IN ROTATION A, 1928–32

Crop	Percentage of moisture				
	May 1	June 15	July 15	Aug. 15	Oct. 1
1928—					
Summerfallow	21.1	19.9	25.6	23.9	18.0
Wheat	29.7	22.4	28.5	25.5	16.8
Corn	26.4	26.7	29.6	27.5	18.7
Oats and Sweet Clover	24.2	20.9	28.0	20.3	13.6
Sweet Clover	28.5	23.8	26.8	22.1	13.4
1929—					
Summerfallow	34.1	26.8	25.8	19.8	20.7
Wheat	28.8	22.6	13.9	9.3	14.2
Corn	32.7	28.5	32.2	21.4	17.2
Oats and Sweet Clover	35.2	25.8	19.3	12.7	16.7
Sweet Clover	33.6	21.7	17.2	11.8	15.3
1930—					
Summerfallow	24.6	28.7	24.2	23.1	31.2
Wheat	26.2	26.2	13.4	11.1	24.7
Corn	22.2	26.4	20.6	13.5	26.9
Oats and Sweet Clover	28.1	30.7	18.0	15.5	31.4
Sweet Clover	26.5	29.6	15.5	12.9	28.5
1931—					
Summerfallow	28.3	13.7	27.0	23.0	33.0
Wheat	29.7	19.2	22.6	12.8	29.1
Corn	26.0	17.4	26.3	15.1	28.0
Oats and Sweet Clover	26.6	13.0	16.9	11.4	28.1
Sweet Clover	31.5	16.7	24.9	17.6	33.5
1932—					
Summerfallow	34.3	24.4	25.9	28.7	28.7
Wheat	32.3	30.4	19.3	18.7	21.0
Corn	32.6	30.6	27.8	21.0	18.0
Oats and Sweet Clover	29.4	22.8	13.7	15.6	15.1
Sweet Clover	29.6	17.7	12.5	16.5	15.9

TABLE 5.—AVERAGE MOISTURE CONTENT OF ROTATION A, 1928–32

Crop	Percentage of moisture 0–6″				
	May 1	June 15	July 15	Aug. 15	Oct. 1
Summerfallow	28.5	22.7	25.9	23.7	26.3
Wheat	29.3	24.2	19.5	15.5	21.2
Corn	27.9	25.9	27.3	19.7	21.8
Oats and Sweet Clover	28.7	22.6	19.2	15.1	20.9
Sweet Clover	29.9	21.9	19.4	16.2	21.3

fallow was 31.9 p.p.m. over the 5-year period. This indicates an average loss of approximately 6 p.p.m. from the previous fall. This decrease or disappearance of nitrates from the surface soil between early October and the following spring, may have been due to various causes, the most important of which was probably the effect of leaching in seasons of high fall precipitation. It may be mentioned that the soil of this area is usually frozen between the 1st of November and the 1st of April, and therefore no leaching would occur between these dates.

During the wheat year, rapid disappearance of nitrate nitrogen coincides with the period of most rapid growth. Between the middle of June and the middle of July there was a drop in nitrates from 25.2 p.p.m. to 6.6. Previous to the middle of June, the decrease was about 7 p.p.m. A slight increase in nitrates occurs in the fall of the year after harvesting the crop.

In the corn year, the amount of nitrates remained higher than under any other crop in the rotation. In fact, the nitrate content increased until the middle of July. Since the samples of soil were obtained from between the rows, this increase is unlikely to be representative of actual conditions more directly within the range of the plant roots. Furthermore, conditions with respect to sufficiency of moisture are somewhat more favourable for nitrification under corn than under other crops (Tables 4 and 5, and Figure 1).

Under oats sown down to sweet clover a general decrease of nitrates occurred from early May to the middle of July. However, it may be noted that a slightly greater amount of nitrates was present at the beginning of the oat year than was present in the fall following the corn crop. The fall growth of sweet clover appears to be responsible for the low level at which the nitrate content of the soil remained during the remainder of the season.

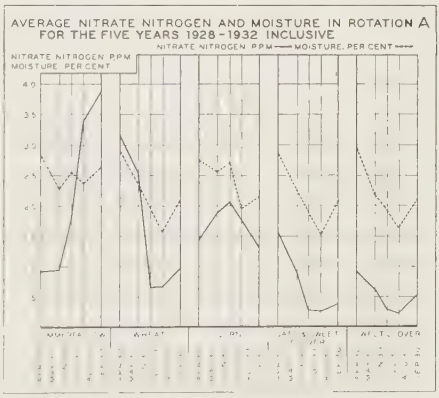

FIGURE 1

During the 5 years, the nitrate content under the sweet clover was consistently low. Again it may be noted that the nitrate content at the beginning of the sweet clover year is somewhat high as compared to the previous fall. In the spring there were 9.2 p.p.m. of nitrates but by August the nitrate content reached the low average of 2.7 p.p.m. A slight increase in nitrates is indicated towards the end of the season.

The highest accumulation of nitrate nitrogen was 68 p.p.m. on summer-fallow in October, 1928. This is considerably higher than appears to be usual since the next highest result is 43 p.p.m. This high accumulation is probably related to the nature of the season of 1928, which was unusually wet and cool during June and July and became warm and comparatively dry towards the fall. Maximum rate of nitrification was delayed to a later period than in the other seasons but proceeded rapidly with favourable

conditions of soil moisture and temperature. A notable decrease in nitrates on the summerfallow occurred in 1931, when a loss of 20 p.p.m. was recorded between August and October. This coincided with heavy rains in September of that year and no doubt was partly due to leaching.

The lowest amount of nitrates was found under sweet clover in August, 1928, and again under oats and sweet clover in July of 1932 when it reached 1.3 p.p.m.

There is a fairly uniform moisture content throughout the summerfallow year period. The low points on the summerfallow plots in June and August probably are a result of cultivation. The moisture curves follow the nitrate curves in a general way during the crop years. The lowest moisture content occurs in August on wheat, oats, and sweet clover, when the average percentage reached about 15%. This is approaching the wilting coefficient of the soil and no doubt nitrification processes would be slowed up or halted entirely at these points. The percentage of moisture tends to be somewhat higher under corn than other crops. However, it is to be noted that the soil samples were taken between the rows and only to a 6-inch depth on this series of plots.

TABLE 6.—NITRATE NITROGEN AT VARIOUS DEPTHS UNDER CONTINUOUS WHEAT AND A ROTATION OF SUMMERFALLOW, WHEAT AND OATS, FOR THE YEARS 1928–1932

Depth	Parts per million									
	May 1	June 15	July 15	Aug. 15	Oct. 1	May 1	June 15	July 15	Aug. 15	Oct. 1
	Wheat, 1928					Wheat, 1929				
0– 6″	8.0	6.7	3.1	1.7	6.3	13.7	2.7	1.2	1.9	3.5
6–12″	4.4	3.1	2.0	2.2	2.9	5.1	1.6	1.1	1.0	3.1
12–18″	3.3	2.9	1.5	1.3	3.0	4.8	1.1	1.6	1.5	5.4
	Wheat, 1930					Wheat, 1931				
0– 6″	8.2	6.7	2.8	2.3	3.9	11.6	11.5	8.5	4.5	13.0
6–12″	2.0	3.4	1.9	1.5	5.7	5.4	5.5	6.9	5.5	23.3
12–18″	2.4	1.8	2.7	2.4	2.2	2.2	5.0	5.1	5.4	6.0
	Wheat, 1932									
0– 6″	12.8	8.1	1.5	1.9	17.0					
6–12″	15.9	13.0	4.3	4.1	6.0					
12–18″	8.3	6.0	1.3	5.9	11.1					
	Summerfallow, 1928					Wheat, 1929				
0– 6″	5.3	7.2	4.5	24.0	50.0	32.4	13.7	2.2	3.0	5.3
6–12″	2.7	3.3	4.8	13.2	19.9	23.4	8.8	3.0	2.8	4.6
12–18″	0.87	2.2	4.7	10.8	15.6	11.6	6.4	3.4	1.6	3.5
	Oats, 1930					Summerfallow, 1931				
0– 6″	8.6	6.7	3.6	2.2	2.5	6.6	9.0	10.4	21.6	14.5
6–12″	4.1	6.4	3.4	2.4	5.7	5.5	5.7	12.3	13.3	25.6
12–18″	2.9	2.5	2.3	2.9	4.5	4.6	5.7	7.0	6.4	7.6
	Wheat, 1932									
0– 6″	12.8	6.9	1.3	5.9	11.1					
6–12″	18.0	16.8	6.7	4.8	11.8					
12–18″	16.8	13.2	7.9	8.0	12.0					

DISCUSSION OF NITRATE AND MOISTURE DATA OF ROTATION S

Samples were taken at the depth 0 to 6″, 6 to 12″ and 12 to 18″ on the summerfallow, wheat, oats, and continuous wheat plots. The nitrate and moisture results are tabulated in Tables 6 and 7, respectively. Samplings were made at the same dates throughout the 5-year period as was done in Rotation A. In general, the results are the same as in Rotation A. However, some additional observations may be made from the results on samples taken at the lower depths. In the fall months of 1928 and 1931, under summerfallow, there is evident a distinct increase of nitrates in the

TABLE 7.—MOISTURE AT VARIOUS DEPTHS UNDER CONTINUOUS WHEAT AND A ROTATION OF SUMMERFALLOW, WHEAT AND OATS FOR THE YEARS 1928–1932

Depth	Percentage of moisture									
	May 1	June 15	July 15	Aug. 15	Oct. 1	May 1	June 15	July 15	Aug. 15	Oct. 1
	Wheat, 1928					Wheat, 1929				
0– 6″	25.0	22.0	24.2	19.0	15.4	27.2	20.9	14.6	10.7	12.7
6–12″	23.0	18.6	22.8	20.4	18.1	20.6	23.1	16.0	13.1	12.2
12–18″	20.0	17.0	21.6	18.7	15.3	23.4	22.2	17.5	13.7	16.1
	Wheat, 1930					Wheat, 1931				
0– 6″	–	26.4	26.3	10.0	24.2	25.0	10.5	19.4	11.4	28.4
6–12″	–	22.4	12.3	12.2	20.0	18.5	10.2	15.6	13.1	24.3
12–18″	–	18.8	13.6	17.8	17.3	17.0	15.8	17.0	14.6	18.8
	Wheat, 1932					Summerfallow, 1928				
0– 6″	31.5	23.8	13.4	16.1	20.3	20.0	21.2	23.0	20.8	17.4
6–12″	28.1	23.0	15.9	14.0	16.6	17.5	18.1	21.8	21.0	15.6
12–18″	21.2	19.0	17.4	16.2	17.2	12.8	15.1	21.2	19.2	19.0
	Wheat, 1929					Oats, 1930				
0– 6″	25.9	18.3	12.4	7.8	14.5	–	20.6	7.6	7.2	21.6
6–12″	23.6	20.4	11.6	9.5	15.0	–	15.8	7.9	8.2	16.5
12–18″	22.5	19.6	11.6	8.4	8.9	–	12.1	7.6	9.2	14.1
	Summerfallow, 1931					Wheat, 1932				
0– 6″	22.1	16.6	20.4	17.6	22.6	26.9	21.3	12.5	14.3	16.5
6–12″	16.1	14.8	19.4	18.0	14.1	24.4	21.6	12.7	9.8	12.3
12–18″	13.1	10.9	16.4	14.9	16.4	21.6	19.7	14.0	10.0	11.3

6 to 12″ horizons and in 1928 also in the 12 to 18″ horizon. As mentioned previously there was above average precipitation during the summer of 1928. Part of the increase in nitrates in the lower layers is therefore undoubtedly due to leaching effects. Subsequent crops fairly well exhausted the nitrate content of the soil down to the 18″ depth. Notable leaching of nitrates on medium to heavy textured soils in this region would only occur when there has been an accumulation of nitrates followed by heavy rains, and then only to relatively shallow depths. It is unlikely that loss of nitrogen by leaching is a serious factor in the depletion of nitrogen fertility in this area.

Under continuous wheat, highest nitrate contents occur in the fall and spring. The crop practically exhausts the soil of nitrates during the

growing season. Whether the growth is retarded owing to lack of nitrates would depend upon the rate at which nitrate production is proceeding, and this in turn will depend upon moisture and temperature conditions. It is generally considered that a wheat crop on summerfallow has not only an advantage due to stored moisture but also because of additional available nutrients of which nitrogen is one.

Nitrate data for the wheat, oats, and summerfallow rotation and continuous wheat, together with rainfall data are presented graphically in Figure 2.

THE EFFECT OF STRAW, MANURE, AND SUPERPHOSPHATE ON NITRATE ACCUMULATION

As previously stated, the plots treated with straw, manure, manure and phosphorus, and phosphorus of Rotation A were selected for sampling as a comparison against untreated plots. The results of nitrate determinations for each crop and treatment were averaged for the 5 years of the rotation and are given in Table 8. The results are graphically presented in Figure 3.

Table 8.—Effects of treatments on nitrate nitrogen, rotation 4, averages for the five years 1928–1932

Treatment	Parts per million									
	April 30	June 15	July 15	Aug. 20	Sept. 30	April 30	June 15	July 15	Aug. 20	Sept. 30
	Summerfallow					Wheat				
None	10.8	9.1	15.4	35.9	38.3	27.6	22.2	7.5	7.2	9.0
Straw	9.0	10.2	16.2	29.9	35.6	26.9	23.5	7.0	5.9	9.2
Manure	9.8	9.9	20.6	36.1	44.6	36.9	27.0	7.6	8.6	13.7
Manure + Phos.	9.5	9.6	21.9	43.0	46.9	38.7	29.1	6.6	8.4	9.6
Phosphorus	8.8	7.8	17.2	29.9	35.3	25.5	20.7	10.1	8.4	10.6
	Corn					Oats and Sweet Clover				
None	22.8	17.5	19.1	17.3	12.8	15.4	10.2	3.5	2.8	3.8
Straw	13.9	16.6	19.8	13.7	12.5	15.9	10.4	2.8	2.7	3.8
Manure	16.0	21.3	22.3	17.7	13.5	15.6	10.3	2.5	3.0	4.4
Manure + phos.	16.5	20.3	23.3	20.9	15.5	18.1	8.6	2.9	3.6	5.0
Phosphorus	13.7	20.6	21.9	20.9	12.4	15.7	9.1	3.1	2.7	3.3
	Sweet Clover									
None	10.2	6.8	3.1	3.8	5.3					
Straw	8.7	6.2	3.5	2.5	5.3					
Manure	9.8	6.4	3.9	2.6	5.4					
Manure + phos.	10.8	6.1	3.4	3.2	4.1					
Phosphorus	8.0	5.9	2.8	2.7	5.2					

The manure and straw were applied in the summerfallow year and ploughed under while the superphosphate was applied to the wheat crop following summerfallowing. The results of the nitrate determinations for each crop and treatment are averaged for the 5 years of the experiment and tabulated in Table 8. In Figure 3, these data are presented in graphic form.

An increase in the rate of nitrification is apparent as a result of manuring. The resultant higher content of nitrate nitrogen is carried over into

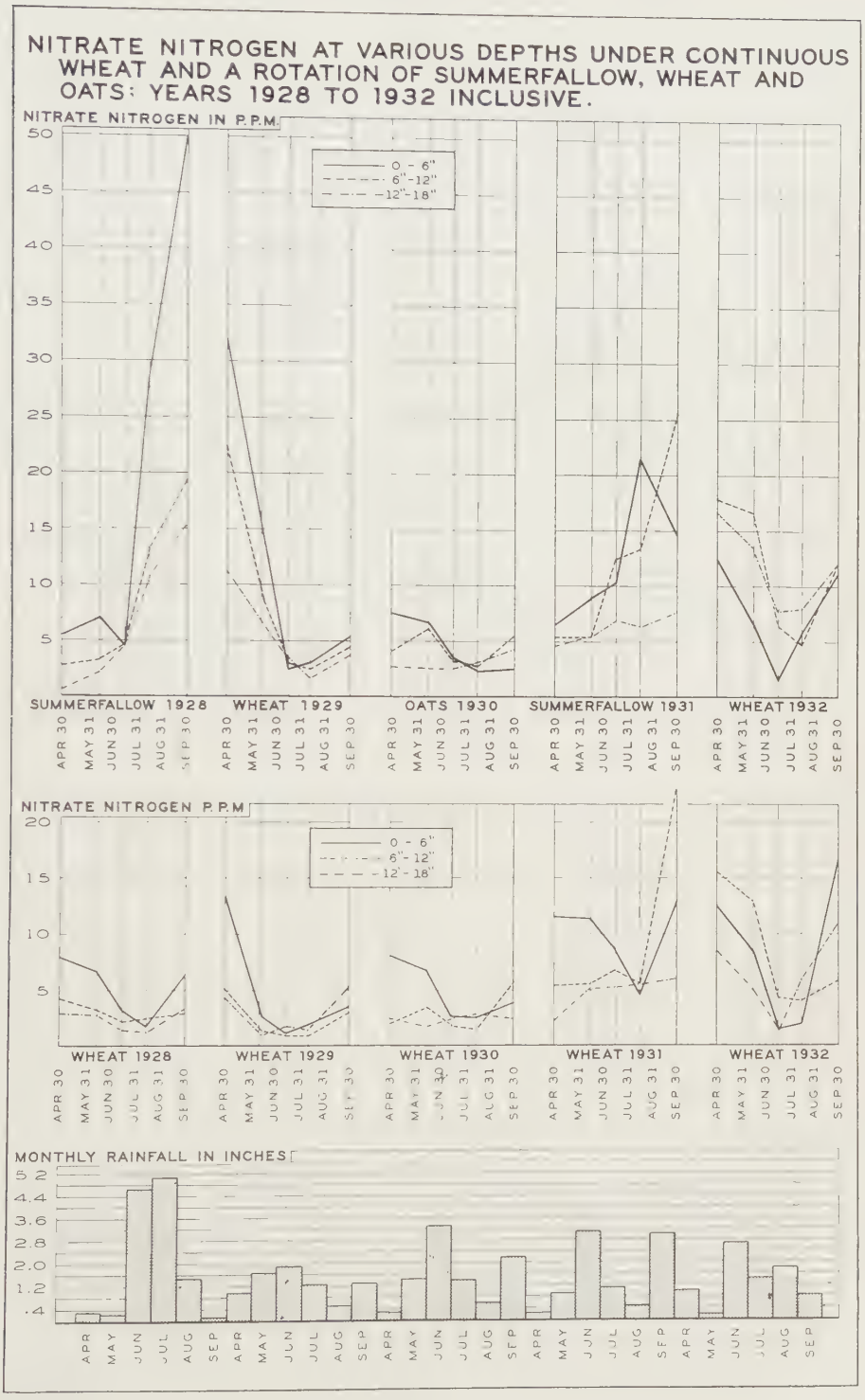
NITRATE NITROGEN AT VARIOUS DEPTHS UNDER CONTINUOUS WHEAT AND A ROTATION OF SUMMERFALLOW, WHEAT AND OATS: YEARS 1928 TO 1932 INCLUSIVE.
NITRATE NITROGEN IN P.P.M.
0 - 6"
6"-12"
12"-18"
SUMMERFALLOW 1928
WHEAT 1929
OATS 1930
SUMMERFALLOW 1931
WHEAT 1932
NITRATE NITROGEN P.P.M
WHEAT 1928
WHEAT 1929
WHEAT 1930
WHEAT 1931
WHEAT 1932
MONTHLY RAINFALL IN INCHES
APR 30
MAY 31
JUN 30
JUL 31
AUG 31
SEP 30

FIGURE 2

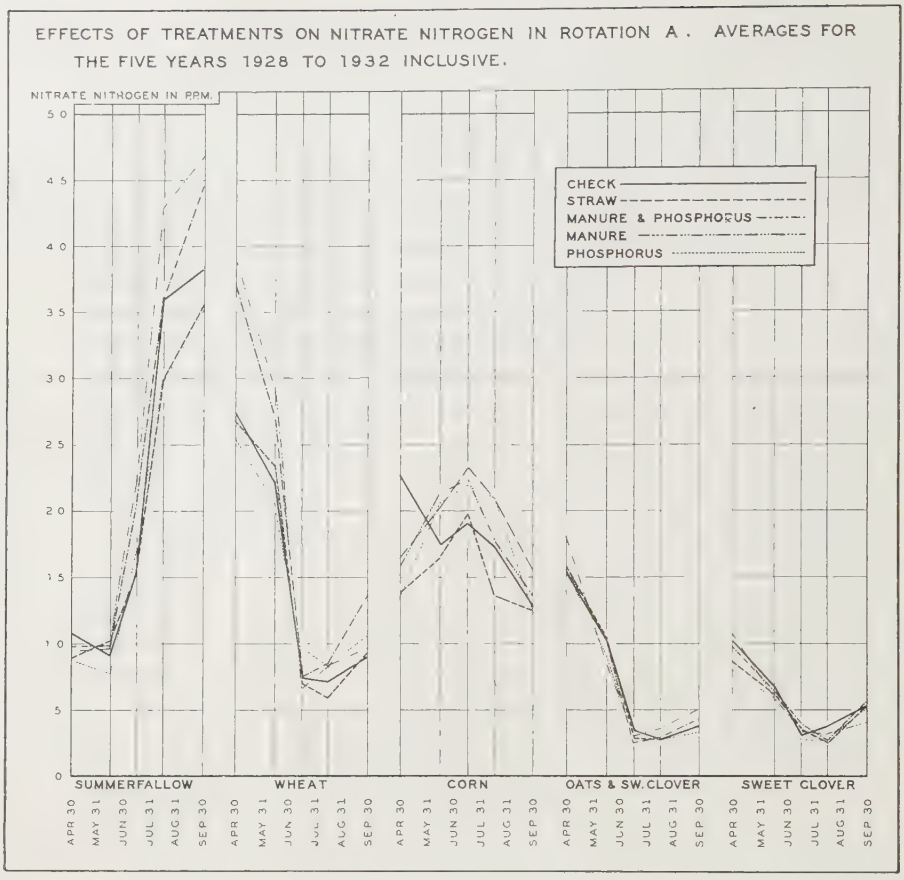

FIGURE 3

the wheat year. During the period of rapid growth the nitrate content of the manured plots was about the same as on the untreated plots, but increased somewhat above the checks throughout the corn year. There is no effect apparent beyond the second year after manuring. The data for plots treated with manure and superphosphate indicate results similar to manure alone although in the summerfallow year the rate of nitrification is somewhat less.

The application of $2\frac{1}{2}$ tons of straw, while small in amount, apparently has slightly decreased the amount of nitrate accumulation during the summerfallow period. No effect beyond the end of the summerfallow season is apparent. These results indicate that normal amounts of strawy residues may decompose sufficiently during a summerfallow period so that no adverse effects on the following crop is likely to occur due to reduced availability of nitrogen. Observation in this area leads to the conclusion that detrimental effects occur where undue amounts of strawy residues are incorporated into the soil, unless a summerfallow period intervenes before the next crop is grown. A temporary reduction in the nitrate content of the soil is very likely one of the causes for reduced yields in such cases.

In the summerfallow year the superphosphate treated plots accumulated slightly less nitrates than the checks. It is difficult to explain the result since the superphosphate was applied 4 years previously in the rotation. During the wheat year when the superphosphate was applied there is little apparent effect. However, there was some increase in the nitrate content in the corn year, although this increase was slight and was only evident in the middle of the season.

SUMMARY

A study of the nitrate content of soil on certain plots at the University of Saskatchewan was begun in 1928 and continued for 5 years. Two experimental fields were included in the study, one being a 5-year rotation of summerfallow, wheat, corn, oats sown to sweet clover, and sweet clover, and the other, summerfallow, wheat and oats, and continuous wheat. The 5-year rotation included certain residue and fertilizer treatments of which applications of straw, manure, manure and superphosphate, and superphosphate were studied for their effect on nitrate content.

There was a considerable accumulation of nitrates during the summerfallow year. The period of most rapid accumulation occurred between the middle of June and the middle of August. Rapid disappearance of nitrates occurred during the period of rapid vegetative growth of wheat following summerfallow. During the corn year the nitrate level remained somewhat higher than for either wheat, oats, or sweet clover. The lowest average nitrogen content occurred during the sweet clover year, with oats and sweet clover intermediate between wheat following summerfallow, and sweet clover.

In the summerfallow, wheat, oats rotation, similar results were obtained, while continuous wheat resulted in generally low nitrate content of the soil throughout the growing season. There was an increase of nitrate content in the soil at the end of the season after the crops had matured, or had been harvested.

The application of barnyard manure resulted in increased production of nitrates during the summerfallow period. The light application of straw had a slight effect in reducing the amount of nitrates produced. There appeared to be little effect of either treatment beyond the early part of the growing season of the wheat year. While some leaching of nitrates occurred during periods of heavy precipitation, loss of nitrogen in this way is not of importance in medium to heavy textured soils of this area, since the nitrates would only leach to relatively shallow depths well within the zone of root development.

ACKNOWLEDGMENTS

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THE RELATIONSHIP OF CERTAIN CHEMICAL CHARACTERISTICS TO THE GEOLOGICAL ORIGIN OF SOME SOUTHERN ONTARIO SOILS[1]

F. F. Morwick[2] and T. J. Heeg[3]
Ontario Agricultural College, Guelph, Ontario

INTRODUCTION

It is now quite generally conceded that climate is the dominant factor governing soil-forming processes over a broad continental area. The changes which have taken place in the formation of our soils from unweathered geological materials have extended over varied lengths of time. The effect of climate becomes more pronounced as the soils grow older, and inversely, the effect of the nature of the parent geological material becomes less as the soil grows older.

Natural geological processes, such as continental glaciation, have disrupted soil-forming processes so that the process had to start all over again. The continental glaciation which scoured the northern part of North America during the Pleistocene Period is comparatively recent, geologically speaking. Hence the soils in this region are young in comparison to those in the non-glaciated region in the southern part of the continent. Water and wind erosion and cultivation are also important factors in disrupting the natural soil-forming processes. In many rolling or hilly cultivated fields the unweathered geological material is exposed at the surface on the hillsides, the natural weathered soil profile having been entirely removed. In less eroded parts of the same field the A_2 or B horizon may be exposed at the surface.

Thus, considering the youthfulness of our Southern Ontario soils and the continual rejuvenation by erosion it is reasonable to expect some correlation between the geological origin and the chemical characteristics.

GEOGRAPHICAL AREAS

For this paper there have been selected three geographical areas which have been mapped in the soil survey and from which chemical data are available on samples taken during the survey. For convenience in presentation, these three areas will be called Niagara Peninsula, Western Ontario and Central Ontario. They are as follows:—

1. *Niagara Peninsula.*—This area includes that part of the Niagara Peninsula above or south of the Niagara Escarpment, including the counties of Welland, Haldimand, the south parts of Lincoln and Wentworth and the east part of Brant. (Most of the Niagara Fruit Belt is below or north of the Escarpment.)

2. *Western Ontario.*—This area includes the Counties of Middlesex and Oxford, and most of the Counties of Huron, Perth and Brant.

3. *Central Ontario.*—This area includes Prince Edward County and the Southern parts of Northumberland and Durham.

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[2] Soil Surveyor, Department of Chemistry.

[3] Research Assistant, Department of Chemistry.

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Geological Origin

The soils in each of these three areas are formed mainly from glacial drift, outwash from it, and glacial lake sediment. The composition of the glacial drift varies considerably in the three areas.

In the Niagara Peninsula it is made up of a large proportion of shale and dolomitic limestone with some sandstone and igneous rocks.

In Western Ontario there is a much larger proportion of dolomitic limestone, and smaller proportion of shale and sandstone.

In Central Ontario the drift is composed mainly of limestone with a considerable admixture of igneous rock presumably containing a fair amount of apatite. Spence (1) in his report on *Phosphate in Canada* notes the occurrence of many small apatite mines in Frontenac, Leeds and Lanark Counties as well as in the Quebec Region just North of Ottawa and Hull. Taylor (2), Putnam and Chapman (3) and others show the direction of ice movement in that region to have been southwestward and westward. Thus the ice would have scoured off some of the apatite along with the rock debris and we could expect that the glacial drift and outwash from it in the Central Ontario Region should contain a larger proportion of this phosphate-bearing mineral than in some other parts of the province. The following chemical data on the soils of the three areas seem to bear this out.

METHODS

Sampling

During and following the mapping of each of these regions, samples of soil were taken from most of the soil types mapped, larger numbers of samples being taken from the more extensive types. Composite samples were taken from the surface layer to a depth of about five or six inches. These were taken in most cases from pasture fields which had not been artificially improved by manuring, fertilization or reseeding within the previous four or five years. A few of the samples were taken from natural pastures where the forest had been cut off, but the soil had never been ploughed. It was felt that by taking the samples in this way it would be possible to get a fairly accurate picture of the natural fertility of the soil in each region, and in each of the main soil types. The organic soils and some of the poorly drained mineral soils of low agricultural value were not sampled.

Analytical Methods

Reaction was first determined colorimetrically as an aid to grouping soils. The pH values herein recorded are those of the quinhydrone electrode, using a saturated calomel cell and a Leeds and Northrup pH indicator.

The method by Lohse and Ruhnke (4) was used to determine readily soluble phosphorus, and during the past year a number of samples were analyzed by the Neubauer Method as outlined by Thornton (5). This latter method serves as a check on the first, being a biological extraction of the available nutrients.

To measure the available potassium content two methods were used. The first method follows that devised by Schollenberger (6) using neutral normal ammonium acetate with a 10-minute extraction. Samples in 1935 and 1936 were read colorimetrically according to the method of Jacobs

and Hoffman (7), but in 1937 the volumetric method of Volk and Truog (8) was followed. A comparison of the methods of reading, before this change, showed no appreciable difference between them. The titration method was adopted because of the difficulty of reading a green colour in the colorimeter and to eliminate the necessity of expensive centrifuge tubes and the long procedure of centrifuging.

Neubauer analysis for potash was also carried out and should serve a useful purpose as a guide to the accuracy of the determination of available potash by the other method.

It will be noted in the tables that the phosphorus results are expressed in one case as P and in the other as P_2O_5, and that the potash results are all expressed as K_2O. While the criticism might be made that all results should be expressed as oxides, or as element, the authors feel that it is better to use the same expression as that of the original method. Those who are familiar with the methods can then better appreciate the values given if the expression is that with which they have been working.

All phosphorus and potassium are expressed in pounds per acre, assuming 2,000,000 lbs. to be the weight of an acre–6 inches of soil.

Requirements for Good Crop Growth

This work has not been closely correlated with crop response but for the purpose of comparing soil types, soil groups, and regions use has been made of standards set by other workers whose analytical methods have been used in this laboratory.

Optimum reaction for farm crop plants has been discussed by many workers. While it varies within certain limits, it is generally recognized that somewhere near the neutral point is most suitable for most of the common farm crops in this region.

Lohse and Ruhnke (4) state that, "It has been the experience of this institution [Ontario Agricultural College] that soil samples containing 30 mgm. or less of P per 1,000 grams of soil (60 lbs. per acre) appear to indicate very marked phosphate deficiency."

It has also been recognized that the $KHSO_4$ method gives higher results in alkaline soils even though there may still be a marked phosphate deficiency. If the Neubauer results may be considered as a standard this is clearly indicated by a study of the following tables, particularly Table 2B.

Thornton (5) specifies that, "Soils are considered deficient unless the Neubauer values for available phosphorus and potassium are above 80 lbs. P_2O_5, and 200 lbs. K_2O per acre."

Volk and Truog (8), in discussing the ammonium acetate method for determining available potash, state that, "Although approximately 200 lbs. per acre for the ploughed layer of loam soils has been set as the minimum amount which probably suffices, a number of factors may alter this amount. Approximately this amount is required in the Northern States for the production of maximum yields of corn, small grains and clover. . . . . Potatoes, tobacco, sugar beets and other truck crops require more than 200 lbs. per acre for maximum growth."

ANALYTICAL RESULTS

For the presentation of results the samples from each of the three regions are divided into three groups as shown in Table 1.

TABLE 1

Group I—Loam to clay loam and clay soils, with fair to good natural drainage.
Group II—Sandy soils with fair to good natural drainage.
Group III—Soils with poor natural drainage.

Niagara Peninsula

Group I	86% of area or	1,090 square miles.
Group II	4% of area or	50 square miles.
Group III	10% of area or	130 square miles.
Total		1,270 square miles.

Western Ontario

Group I	70% of area or	2,490 square miles.
Group II	16% of area or	550 square miles.
Group III	14% of area or	520 square miles.
Total		3,560 square miles.

Central Ontario

Group I	55% of area or	420 square miles.
Group II	35% of area or	270 square miles.
Group III	10% of area or	80 square miles.
Total		770 square miles.

TABLE 2A.—AVERAGE ANALYSES OF THE NIAGARA PENINSULA SAMPLES FOR pH AND PHOSPHORUS

Soil type	Number of samples	pH	$KHSO_4$ P. lbs. per acre	Neubauer P_2O_5 lbs. per acre	
Group I					
Brantford loam	4	6.56	60	–	(0)*
Brantford clay loam	11	6.35	42	36	(4)
Caistor clay loam	9	5.47	27	5	(4)
Farmington clay loam	4	6.38	50	–	(0)
Haldimand clay	26	5.51	13	13	(8)
Niagara clay	6	5.37	20	17	(3)
Oneida loam	5	6.70	47	7	(2)
Oneida clay loam	11	5.72	19	23	(4)
Perth clay loam	2	6.64	32	–	(0)
Tuscola silt loam	7	6.52	140	4	(3)
Welland clay	15	5.42	23	11	(5)
Total samples and weighted average for group	100	5.83	34	15	(33)
Group II					
Berrien sandy loam	11	6.24	24	5	(4)
Fonthill loam	7	5.95	61	47	(3)
Pelham sandy loam	6	5.66	91	31	(4)
Total samples and weighted average for group	24	6.01	52	26	(11)
Group III					
Colwood loam	4	7.33	229	35	(2)
Granby sandy loam	2	8.04	173	0	(1)
Jeddo clay	9	5.49	108	17	(3)
Toledo clay	3	6.99	151	20	(2)
Wauseon sandy loam	7	6.38	102	7	(4)
Total samples and weighted average for group	25	6.43	131	16	(12)
Total samples and weighted average for Niagara Peninsula	149	5.95	54	17	(56)

*Figures in parentheses indicate the number of samples analysed by the Neubauer method.

Discussion of Table 2A

Most of the surface soils in the Niagara Peninsula, where not eroded, are quite acid in reaction. Those near neutral or alkaline occur mostly in Moulton and Wainfleet Townships within the lake bed of glacial Lake Lundy. They are, no doubt, influenced by the limestone sediment washed into the lake by the predecessor of the Grand River.

The phosphorus levels are very low in this area. The highest levels obtained by the $KHSO_4$ method are in the poorly drained group and the Tuscola silt loam which has only fair natural drainage. The Neubauer analysis shows low amounts of available phosphorus in all groups.

TABLE 2B.—AVERAGE ANALYSES OF WESTERN ONTARIO SAMPLES FOR pH AND PHOSPHORUS

Soil type	Number of samples	pH	$KHSO_4$ P. lbs. per acre	Neubauer P_2O_5 lbs. per acre	
Group I					
Guelph loam	42	7.26	52	17	(9)*
Haldimand silt loam	2	6.75	49	–	(0)
Haldimand clay loam	9	6.63	46	–	(0)
Huron clay loam	70	7.34	62	14	(10)
London loam	40	7.17	94	13	(7)
Perth clay loam	60	7.40	97	16	(6)
Dumfries loam	4	7.25	94	–	(0)
Total samples and weighted average for group	227	7.28	75	15	(32)
Group II					
Berrien sandy loam	16	6.60	23	–	(0)
Burford loam	18	7.27	56	–	(0)
Fox sandy loam	4	7.39	83	–	(0)
Fox sand	24	6.37	56	–	(0)
Oshtemo sand	5	6.31	86	18	(4)
Dumfries sandy loam	6	6.91	62	–	(0)
Total samples and weighted average for group	73	6.75	53	18	(4)
Group III					
Brookston clay loam	13	7.32	71	–	(0)
Brookston loam	6	7.37	265	–	(0)
Brookston silt loam	2	6.66	151	–	(0)
Granby sandy loam	5	7.53	71	–	(0)
Gilford loam	2	7.52	70	–	(0)
Total samples and weighted average for group	28	7.34	118	–	(0)
Total samples and weighted average for Western Ontario	328	7.18	74	15	(36)

*Figures in parentheses indicate the number of samples analysed by the Neubauer method.

Discussion of Table 2B

The soils of Western Ontario have a higher lime content than those of the Niagara Peninsula, and are more alkaline in reaction. The sandy soils are usually slightly more acid than the heavier soils. The poorly drained soils are usually more alkaline.

The phosphorus levels by the $KHSO_4$ method are somewhat higher, in Groups I and III, than in the Niagara Peninsula, but the Neubauer results completed at this time show again, very low levels of available phosphorus.

TABLE 2C.—SHOWING THE AVERAGE ANALYSES OF CENTRAL ONTARIO SAMPLES FOR pH AND PHOSPHORUS

Soil type	Number of samples	pH	$KHSO_4$ P. lbs. per acre	Neubauer P_2O_5 lbs. per acre	
Group I					
Bondhead loam	17	7.16	143	39	(5)*
Farmington loam	6	7.62	172	–	(0)
Farmington rubbly loam	1	8.23	132	–	(0)
Farmington clay loam	2	7.78	320	–	(0)
Newcastle loam	16	6.94	188	70	(4)
Newcastle silt loam	9	7.40	224	48	(3)
Otonabee loam	2	7.94	197	–	(0)
Vergennes loam	2	7.26	124	–	(0)
Vergennes silt loam	4	7.28	343	–	(0)
Vergennes clay loam	6	6.57	148	30	(1)
Total samples and weighted average for group	65	7.21	189	50	(13)
Group II					
Brighton sand..	15	6.52	110	67	(5)
Cramahe gravelly loam	2	8.08	221	–	(0)
Dundonald sandy loam	30	7.07	142	81	(6)
Tecumseth sandy loam	10	7.27	86	22	(3)
Newcastle fine sandy loam	6	7.06	101	–	(0)
Pontypool sand	3	7.22	119	–	(0)
Total samples and weighted average for group	66	7.02	124	63	(14)
Group III					
Toledo clay loam	1	7.15	580	–	(0)
Total samples and weighted average for Central Ontario	132	7.12	160	57	(27)

*Figures in parentheses indicate the number of samples analysed by the Neubauer method.

Discussion of Table 2C

Most of the soils of the Central Ontario region are near neutral or alkaline in reaction. The most acid types are the well-drained, non-eroded sandy types, and the marine sediments (Vergennes types) which occur at the eastern end of the district studied. The more alkaline types are well-drained soils with very shallow profiles (Otonabee loam, and Cramahe gravelly loam) and the Farmington types which have limestone bedrock at very shallow depths. They usually have carbonates in the ploughed layer.

The phosphorus levels are higher by both methods than in the soils of the other two areas studied. It is recognized that the $KHSO_4$ method usually gives somewhat higher results in alkaline soils, but in comparing Central Ontario results with Western Ontario, we find almost equal pH values, but much higher phosphorus levels in Central Ontario. The Neubauer method shows considerably higher amounts of available phosphorus in the Central Ontario region than in the other two regions.

TABLE 3A.—AVERAGE ANALYSES OF THE NIAGARA PENINSULA SAMPLES FOR POTASSIUM

Soil type	Number of samples	$NH_4C_2H_3O_2$ repl. K_2O lbs. per acre	Number of samples	Neubauer K_2O lbs. per acre
		Group I		
Brantford loam	4	125	–	–
Brantford clay loam	11	287	4	370
Caistor clay loam	9	225	4	157
Farmington clay loam	4	447	–	–
Haldimand clay	26	308	8	378
Niagara clay	6	306	3	405
Oneida loam	5	182	2	73
Oneida clay loam	11	220	4	316
Perth clay loam	2	340	–	–
Tuscola silt loam	7	210	3	333
Welland clay	15	337	5	240
Total samples and weighted average for group	100	278	33	302
		Group II		
Berrien sandy loam	11	180	4	178
Fonthill loam	7	176	3	150
Pelham sandy loam	6	279	4	123
Total samples and weighted average for group	24	187	11	150
		Group III		
Colwood loam	4	182	2	278
Granby sandy loam	2	89	1	132
Jeddo clay	9	420	3	335
Toledo clay	3	226	2	409
Wauseon sandy loam	7	145	4	110
Total samples and weighted average for group	25	260	12	249
Total samples and weighted average for Niagara Peninsula	149	261	56	261

Discussion of Table 3A

The heavier soils in this region appear to be well supplied with potassium according to the standards set by the authors of the analytical

methods used. The sandy soils are deficient, but are not as low in available potassium as the sandy soils in the other two areas.

TABLE 3B.—AVERAGE ANALYSES OF THE WESTERN ONTARIO SAMPLES FOR POTASSIUM

Soil type	Number of samples	$NH_4C_2H_3O_2$ repl. K_2O lbs. per acre	Number of samples	Neubauer K_2O lbs. per acre
		Group I		
Guelph loam	42	159	9	250
Haldimand silt loam	2	300	–	–
Haldimand clay loam	9	249	–	–
Huron clay loam	70	238	10	244
London loam	40	176	7	256
Perth clay loam	60	225	6	209
Dumfries loam	4	107	–	–
Total samples and weighted average for group	227	208	32	242
		Group II		
Berrien sandy loam	16	118	–	–
Burford loam	18	113	–	–
Fox sandy loam	4	150	–	–
Fox sand	24	57	–	–
Oshtemo sand	5	54	4	127
Dumfries sandy loam	6	54	–	–
Total samples and weighted average for group	73	87	4	127
		Group III		
Brookston clay loam	13	288	–	–
Brookston loam	6	149	–	–
Brookston silt loam	2	158	–	–
Granby sandy loam	5	73	–	–
Gilford loam	2	55	–	–
Total samples and weighted average for group	28	194	–	–
Total samples and weighted average for Western Ontario	328	180	36	229

Discussion of Table 3B

The heavy soils in this area are also fairly well supplied with potassium according to these methods of analysis, but the sandy soils are deficient. The loam soils are also somewhat deficient according to the ammonium acetate method.

The potassium levels in the area as a whole are considerably lower than in the Niagara Peninsula.

TABLE 3C.—AVERAGE ANALYSES OF THE CENTRAL ONTARIO SAMPLES FOR POTASSIUM

Soil type	Number of samples	$NH_4C_2H_3O_2$ repl. K_2O lbs. per acre	Number of samples	Neubauer K_2O lbs. per acre
Group I				
Bondhead loam	17	130	5	82
Farmington loam	6	243	–	–
Farmington rubbly loam	1	122	–	–
Farmington clay loam	2	242	–	–
Newcastle loam	16	177	4	249
Newcastle silt loam	9	211	3	257
Otonabee loam	2	182	–	–
Vergennes loam	2	136	–	–
Vergennes silt loam	4	232	–	–
Vergennes clay loam	6	338	1	224
Total samples and weighted average for group	65	194	13	185
Group II				
Brighton sand	15	78	5	86
Cramahe gravelly loam	2	101	–	–
Dundonald sandy loam	30	84	6	78
Tecumseth sandy loam	10	100	3	93
Newcastle fine sandy loam	6	111	–	–
Pontypool sand	3	49	–	–
Total samples and weighted average for group	66	87	14	84
Group III				
Toledo clay loam	1	282	–	–
Total samples and weighted average for Central Ontario	132	142	27	133

Discussion of Table 3C

The average potassium levels for the clay loam and silt loam soils are all above the 200 level, but in the sandy soils they are low to very low. Most of the loam soils are also in the deficient class.

The average for the area is well below the other two areas.

TABLE 4.—AVERAGE POTASSIUM ANALYSES OF TEXTUAL GROUPS FROM EACH OF THE THREE REGIONS

Region	Method	Clay soils	Silt and clay loams	Loams	Sands and sandy loams
Niagara Peninsula	Am. Ac.*	330 (59)†	262 (44)	163 (13)	184 (33)
	Neubauer	348 (21)	291 (15)	176 (4)	138 (16)
Western Ontario	Am. Ac.	– –	231 (156)	161 (94)	88 (78)
	Neubauer	– –	231 (16)	252 (16)	127 (4)
Central Ontario	Am. Ac.	– –	255 (22)	165 (44)	86 (66)
	Neubauer	– –	249 (4)	156 (9)	84 (14)
Weighted averages	Am. Ac.	330 (59)	240 (222)	163 (151)	105 (177)
	Neubauer	348 (21)	266 (32)	212 (29)	114 (34)

*Am. Ac. means Ammonium Acetate.

†Figures in parentheses following the analytical value refer to the number of samples on which the average was taken.

Discussion of Table 4

In a comparison of the three areas by groups, we find the largest amounts of available potassium in the Niagara Peninsula. The difference between regions, however, is not as great as the difference between textural groups. In this table the samples from each area are re-grouped according to texture only. There is a good correlation between potassium levels, and textural groups. The average analyses of all the clay soils, and the silt and clay loams are well above the 200 level while most of the loams, and all of the sandy loams and sands are considerably lower.

SUMMARY

1. The soils from three regions in Southern Ontario which have been surveyed and mapped, have been studied. These three regions have been designated as Niagara Peninsula, Western Ontario and Central Ontario.

FIGURE 1. Outline map of southern Ontario showing the areas studied, and the location of samples.

2. The soils of the Niagara Peninsula are much more acid than those of Western Ontario or Central Ontario, due in part at least, to the smaller proportion of limestone and larger proportion of shale in the parent soil material. (See Figure 2.)

3. There are greater amounts of readily soluble and available phosphorus in the Central Ontario soils than in Western Ontario or the Niagara Peninsula, probably due to a larger amount of apatite in the parent soil material. (See Figure 3.)

4. There are larger amounts of available potassium in the Niagara Peninsula soils than in the other two areas. The Niagara Peninsula is

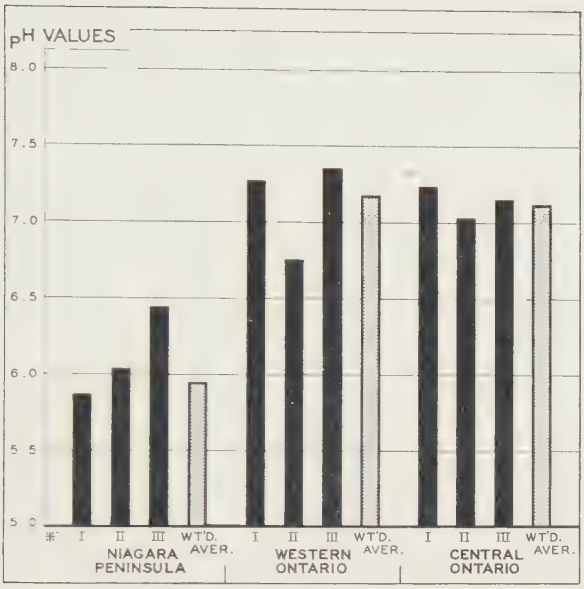

FIGURE 2. pH values of soils from three Ontario regions. Roman numerals refer to soil groups as designated in Table 1. "Wt'd aver." refers to "Weighted average".

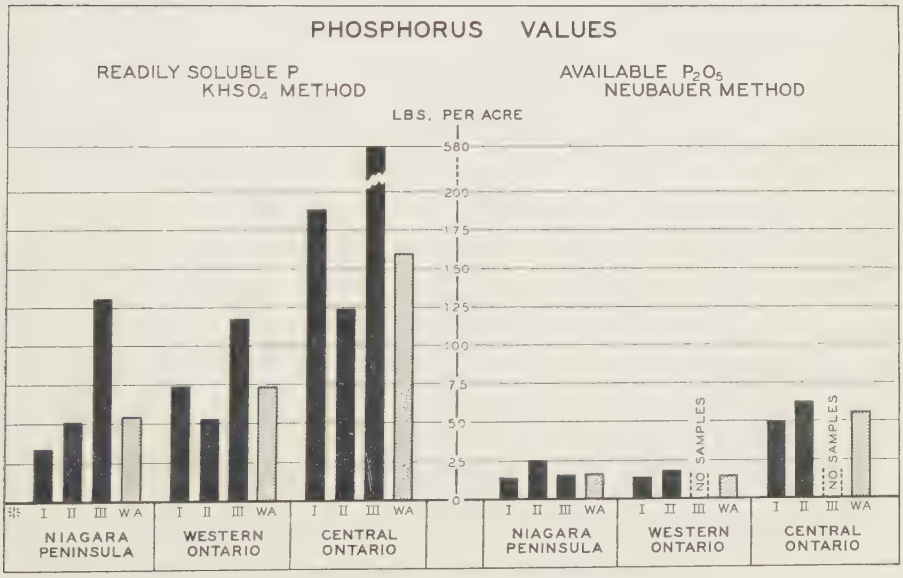

FIGURE 3. Phosphorus values of soils from three Ontario regions. Roman numerals refer to soil groups as designated in Table 1. "W.A." refers to "Weighted Average".

made up of a larger proportion of heavy soils, and also contains more shale in the parent soil material. (See Figure 4.)

5. There is a direct relationship between available potassium content and texture, the heavier soils containing much larger amounts. (See Figure 5.)

6. The weighted average analyses from the preceding tables are presented in the accompanying graphs.

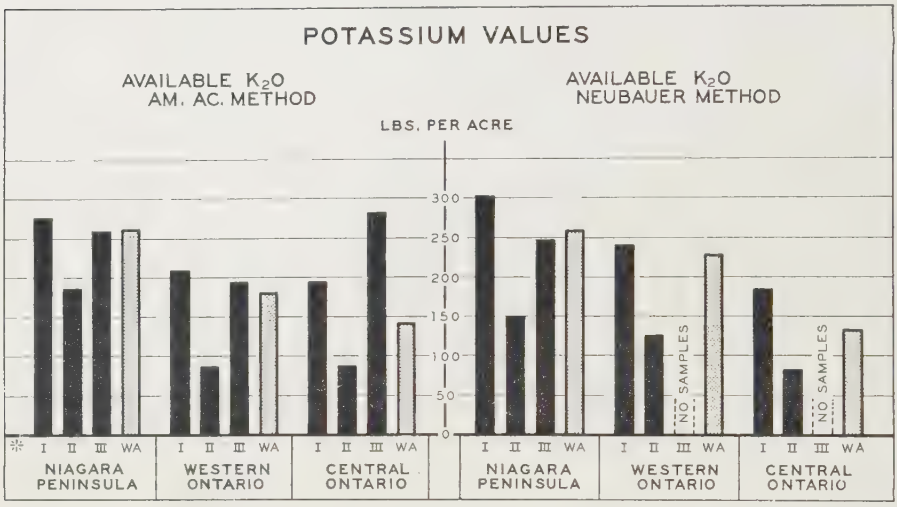

FIGURE 4. Potassium values of soils from three Ontario regions. Roman numerals refer to soil groups as designated in Table 1. "W.A." refers to "Weighted Average".

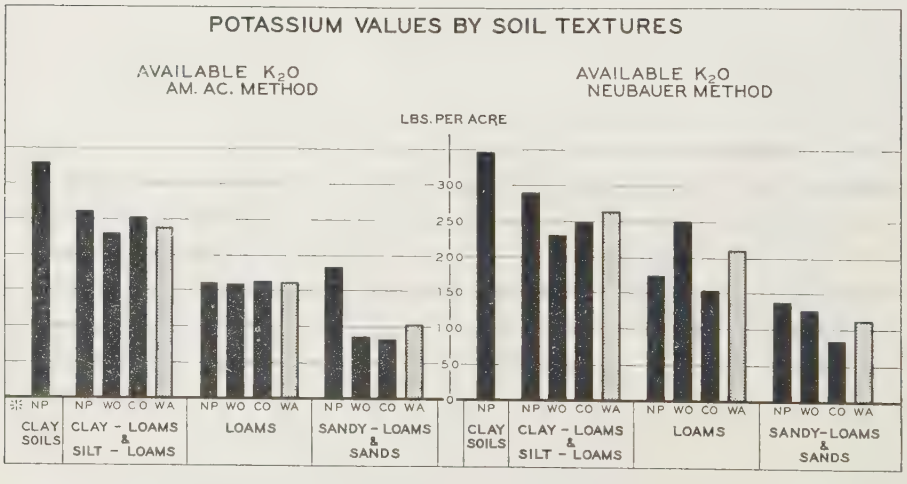

FIGURE 5. Potassium values by soil textures from three Ontario regions. N.P. = Niagara Peninsula, W.O. = Western Ontario, C.O. = Central Ontario, W.A. = Weighted Average.

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POTASSIUM STUDIES IN ONTARIO FLUE-CURED TOBACCO SOILS[1]

K. G. McPhee,[2] N. T. Nelson,[3] G. N. Ruhnke[4]
Ontario Agricultural College, Guelph, Ontario

The flue-cured soils of Ontario are found in two areas: the Old Belt of Essex and Kent; and the New Belt which lies chiefly in Norfolk and Elgin Counties, with smaller areas in south Oxford and Brant Counties. The importance of the Old Belt in the production of flue-cured tobacco has been rapidly superseded in the past few years by production in the New Belt, until at the present time more than 90% of Ontario's flue-cured tobacco is grown in the latter area. Not more than half a dozen soil types in this area are considered well adapted for flue-cured tobacco production. Over 75% of this land is comprised of the two main types, Plainfield sand and Fox coarse sand. Fox gravelly loam, Fox fine sandy loam, and Oshtemo sand are also relatively important in the industry, with Fox sandy loam being used to a smaller extent. Results of studies on four of these main types are reported in the following article.

The important physical properties of soils suited to flue-cured tobacco growing are open texture and looseness in the upper layers, and good drainage in the lower regions. The open texture of the sandy soils encourages the development of a healthy vigorous root system, and at the same time gives excellent drainage and aeration. These effects are desirable if best results are to be obtained. The previously mentioned soil types are comparatively well adapted for tobacco production.

The investigation of the potassium relation to flue-cured tobacco was carried on by means of plot studies and potassium fixation work on the main types of tobacco soils. In connection with this latter phase, the literature dealing with the problem of potassium fixation was studied. Most of the work seems to have centred on the effect on fixation of applications of limestone and other calcium compounds to the soil. The results have been rather conflicting.

Plummer (7) in his investigations found that lime as Ca $(HCO_3)_2$ did not appear to increase the solubility of soil potash in N/5 HNO_3. Haskell (3) working with subsoil potash found that lime in the quantities applied decreased the yield. Shedd of Kentucky (8) states that $CaCO_3$ had a tendency to depress the solubility of potassium. Volk (9) working on Wisconsin soils discovered that most soils after treatment with three tons of $Ca(OH)_2$ per acre fixed more potassium than those not treated with $Ca(OH)_2$. MacIntyre and others (6) in lysimeter studies at Tennessee report that application of CaO to the soil had a repressive effect on the solubility of soil potassium.

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[1] Article based on thesis submitted by K. G. McPhee to the Department of Chemistry, University of Toronto, in partial fulfillment of degree of M.S.A. The work was done under a co-operative arrangement between the Tobacco Division of the Central Experimental Farm, Ottawa, Ontario, and the Department of Chemistry, Ontario Agricultural College, Guelph, Ontario.

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[2] Graduate student with Tobacco Division of the Central Experimental Farm, 1935–37. Now with Chocolate Products Ltd., Toronto, Ontario.

[3] Chief of Tobacco Division, Central Experimental Farm, Ottawa, Ontario.

[4] Professor of Chemistry, Ontario Agricultural College, Guelph, Ontario.

On the other hand, Jenny and Shade (5) at Missouri found that: "In every case the addition of $CaCO_3$ to the soil liberated large amounts of potassium". In support of this side of the contention, Abel and Magistad (1) working with Hawaian soils, state that: "about one hundred pounds of K_2O per acre-foot was made available from the non-replaceable sources annually in the case of limed soils, and about seventy-five pounds in the case of natural acid soils".

It appears that in the majority of cases investigated recently, lime has caused potassium to become less available. The problem, however, is by no means settled and it appears impossible to apply any general rule to the effect of lime treatment of soils. Similar treatments on different soils do not always give similar results. For that reason it is desirable to settle each case on its own merits.

GENERAL STUDIES ON NORFOLK COUNTY TOBACCO SOILS

The investigations made on Norfolk tobacco soils included the determination of potassium levels in three different types of soils and fixation studies on Fox coarse sand, Fox gravelly loam, Plainfield sand, and Fox fine sandy loam.

Method of Analysis

The determination of both exchangeable and water-soluble potassium in the soil was based on the method outlined by Jacobs and Hoffman (4). This method had been adapted to soils by Ruhnke and Lohse of the Department of Chemistry, Ontario Agricultural College, Guelph, Ontario.

Exchangeable potassium was determined by extracting the potassium from the soil with neutral normal ammonium acetate. In determining water-soluble potassium, the same procedure exactly was employed, but distilled water was substituted for ammonium acetate.

The extraction of potassium from the soil was made by shaking 25 gms. of soil with 100 cc. of extractant for 10 minutes. At the end of the time the mixture was thrown on a filter and leaching with the extractant continued with another 100 cc. portion. The volume was finally made up to 250 cc. A suitable aliquot was evaporated to dryness and the organic matter burned off. The residue was taken up with 5 cc. of water, centrifuged, and a 2 cc. portion drawn off. The potassium in this portion was precipitated in centrifuge tubes as the cobalti-nitrite by the addition of sodium cobalti-nitrite solution, and washed several times with 50% alcohol with centrifuging between washings. When washed free of excess sodium cobalti-nitrite, the precipitate was dissolved in hot water, the volume made up to 4 cc. and cooled. After cooling, 1 cc. of choline hydrochloride and 1 cc. of potassium ferrocyanide solutions were added to each tube. As a result of these additions, a green colour was developed whose concentration was in proportion to the amount of potassium present. These solutions were compared in a colorimeter with potassium standards which had undergone the same treatment as the unknown solutions, and the amount of potassium determined by means of comparison with standard curves. All determinations were done in duplicate. Those which showed a difference of less than 10% were taken as satisfactory for this work.

Investigation of the Exchangeable Potassium in Principal Flue-Cured Tobacco Soil Types

The work done on this particular phase was not extensive in character. The amount of exchangeable potassium in samples of the three most important flue-cured tobacco soil types in the New Belt was determined. These samples were of surface soil taken from what were considered to be representative areas of Fox coarse sand, Fox gravelly loam, and Plainfield sand, and were taken in the spring of the year before any fertilizer had been applied. Twenty-four samples of Fox coarse sand were examined for their potassium content. The levels of exchangeable potassium in these samples varied from 25 p.p.m. to 60 p.p.m. with an average level of 36 p.p.m.

Table 1. — Exchangeable potassium in samples of Plainfield sand

Plot No.	Exchangeable K in p.p.m.
1	56
7	56
16	52
17	57

The figures for exchangeable potassium in Fox gravelly loam and Plainfield sand are shown in the following tables.

The average level for exchangeable potassium in this soil type was found to be 55 p.p.m.

The average level for exchangeable potassium in Fox gravelly loam was 47 p.p.m.

Table 2. — Exchangeable potassium in samples of Fox gravelly loam

Plot No.	Exchangeable K in p.p.m.
5	54
8	43
13	44
17	48

All three of these soils, with average levels of 36 p.p.m., 55 p.p.m., and 47 p.p.m. were much lower in potassium than is considered desirable even for general crops. For such crops as flue-cured tobacco, 200 p.p.m. of exchangeable potassium is probably near the desirable level. These results indicate that the levels of potassium in unfertilized soils are far from adequate for the production of a crop of flue-cured tobacco. Since the areas of these types compose over 80% of the flue-cured tobacco soils in the New Belt, it is readily seen that the addition of potassium to the soils is an essential part of tobacco production.

Potassium Fixation Studies on Four Soil Types

The relative fixation powers of the most important tobacco producing soils in Norfolk were determined by a laboratory set-up. The increased amounts of potassium in fertilizers for flue-cured tobacco give rise to the question of what is likely to happen to potassium added to the different types of soils on which tobacco is grown in this locality.

Treatment of Soils

Four different soil types, Fox coarse sand, Fox gravelly loam, Plainfield sand, and Fox fine sandy loam were studied. In deciding upon the procedure for this work, the methods used by Volk (9) were taken into consideration. Duplicate soil samples were treated with potassium sulphate at the rate of 1,000 pounds of K per acre. Other duplicate samples

were treated with lime at the rate of 1,000 pounds per acre. The potassium in all cases was added as standard solution. The lime, which was added as pure $CaCO_3$, was thoroughly mixed with the dry soil before adding the potassium. These treated soils were incubated at a temperature between 60° C. and 70° C. They were left for 7 days during which time they were wetted and dried 4 times. Other samples treated with potassium in the same way were run singly, and incubated for periods of 14 and 28 days, being wetted and dried regularly. This was done in order to ascertain if further fixation took place.

Checks were run consisting of soils which had no additions whatever, and soils to which lime alone was added at the rate of 1,000 pounds per acre. All conditions were kept as nearly like those for treated soils as possible, the checks being incubated for 7 days. In this way a comparison of the effect of wetting and drying, incubation, etc., on the untreated soils and on treated soils, was made.

Determinations for exchangeable and water-soluble potassium and also for pH were made on all treated soils, and on the original soils which had been used for this fixation work. Because of the active part which soil colloids are considered to play in the fixation of cations in the soil the total colloids in the 4 soils under consideration were determined.

Methods of Analysis

The exchangeable potassium in these fixation studies extracted from the soil with neutral normal ammonium acetate was determined in the same way as previously outlined. In determining the water-soluble potassium the only difference was in the method of extraction. Distilled water was used instead of ammonium acetate. Total colloids were determined by the use of the hydrometer method of mechanical analysis of soils as developed by G. J. Bouyoucos (2).

Results of Analysis

The results of the mechanical analysis of soils are given in Table 3.

It is apparent that Fox gravelly loam is definitely higher in total colloids and definitely lower in its content of sand than the other three soils. For this reason it is to be expected that greater fixation of potassium would occur in the Fox gravelly loam type.

TABLE 3

Soil type	Sand, %	Total colloidal material, %
Plainfield sand	87	9.5
Fox coarse sand	87	8.0
Fox fine sandy loam	81	9.5
Fox gravelly loam	75	15.5

The pH values and the water-soluble and exchangeable potassium contents of the different soil samples are given in Table 4.

Treatment of Data

Since the results shown in this table were too extensive to be treated in one discussion, the treatment of data was divided into several sections.

The amount of fixation of potassium by the different soil types treated with potassium alone, and with lime and potassium, and incubated for 7

TABLE 4.—POTASSIUM FIXATION STUDIES

Soil types	Original soils			Incubated 7 days												Incubated 14 days			Incubated 28 days		
				Untreated checks			Checks treated with lime at rate of 1000 lb. per acre			Soils treated with K at 1000 lb. per acre			Soils treated with K at 1000 lb. per acre. Lime at 1000 lb. per acre			Soils treated with K at rate of 1000 lb. per acre			Soils treated with K at rate of 1000 lb. per acre		
	pH	W-S.K	Ex. K	pH	W-S.K	Ex. K	pH	W-S.K	Ex. K	pH	W-S.K	Ex. K	pH	W-S.K	Ex. K	pH	W-S.K	Ex. K	pH	W-S.K	Ex. K
Fox Coarse Sand	5.88	31	66	–	–	–	–	–	–	5.84	332	544	6.08	286	616	6.03	348	617	6.07	256	555
	5.98	29	88	5.91	34	70	6.23	20	71	5.90	320	574	6.20	326	508	–	–	–	–		–
Fox Gravelly Loam	7.47	40	82	–	–	–	–	–	–	7.25	228	430	7.05	196	456	7.19	155	404	7.43	132	394
	7.84	20	98	7.44	16	60	7.48	16	58	7.54	162	458	7.60	153	474	–	–	–	–	–	–
Plainfield Sand	5.62	40	108	–	–	–	–	–	–	5.63	426	582	6.42	418	674	5.72	330	705	6.05	355	666
	5.64	30	110	5.57	32	74	6.36	29	75	5.35	488	–	6.35	–	676	–	–		–	–	–
Fox Fine Sandy Loam	6.11	26	92	–	–	–	–	–	–	5.71	276	560	6.40	298	654	5.90	294	622	5.73	260	640
	6.25	22	92	6.05	24	76	6.22	24	70	5.72	330	–	6.41	298	706	–	–		–	–	–

N.B.—Figures on potassium represent pounds per acre of K in samples.

days was calculated. The amount of fixation was determined by the following formula:—

(lb. per acre K in original soils ± 1,000 lb. K per acre) −
(lb. per acre K in samples obtainable after treatment).

The results obtained by analysis of duplicate treatments did not coincide as closely as might have been expected, but a study of the results revealed that, in spite of discrepancies in duplicate treatments, the same general trend was exhibited when comparisons were made between different treatments, and between soil types. Since this was the case and because it would clarify the treatment of data, the results on duplicate treatments were averaged. In three cases, it was impossible to give results, as the soil sample ran out before checks within the desired limits of accuracy were obtained in making the analysis. In these cases the result of the duplicate is used for comparison.

The results in amount of fixation as non-water-soluble and non-exchangeable potassium are set forth in Table 5.

TABLE 5.—AMOUNT OF POTASSIUM FIXED IN LIMED AND UNLIMED SOILS

Soil type	Unlimed		Limed	
	Non-W-S.K Lbs. per acre	Non-Ex. K Lbs. per acre	Non-W-S.K Lbs. per acre	Non-Ex. K Lbs. per acre
Fox coarse sand	704	518	724	515
Fox gravelly loam	835	646	856	625
Plainfield sand	578	526	622	434
Fox fine sandy loam	721	532	726	412

Amount of fixation occurring both as non-water-soluble potassium and as non-exchangeable potassium is considered. The results are portrayed graphically in Figure 1.

It is evident that more potassium was fixed in the non-water-soluble form than in the non-exchangeable. The portion of added potassium fixed in the non-water-soluble form by treatment was well over 50% in all cases. The portion of added potassium fixed as non-exchangeable potassium was about 50% in the unlimed samples of Fox coarse sand, Plainfield sand, and Fox fine sandy loam. Where the soil had been treated with lime, the amount of fixation in Plainfield sand and Fox fine sandy loam was less. In the case of Fox gravelly loam about 60% of the potassium was fixed and the difference between limed and unlimed samples was comparatively small. These relationships between the potassium

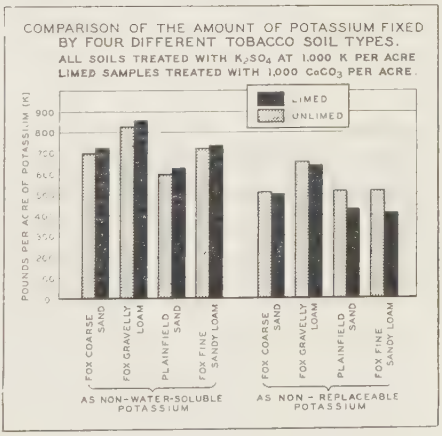
COMPARISON OF THE AMOUNT OF POTASSIUM FIXED BY FOUR DIFFERENT TOBACCO SOIL TYPES.
ALL SOILS TREATED WITH K_2SO_4 AT 1,000 K PER ACRE
LIMED SAMPLES TREATED WITH 1,000 $CaCO_3$ PER ACRE.
LIMED
UNLIMED
POUNDS PER ACRE OF POTASSIUM (K)
900
800
FOX COARSE SAND
FOX GRAVELLY LOAM
PLAINFIELD SAND
FOX FINE SANDY LOAM
AS NON-WATER-SOLUBLE POTASSIUM
AS NON-REPLACEABLE POTASSIUM

FIGURE 1.

added and the portion of added potassium fixed, cannot be expected to hold for fertilizer added in ordinary practice, since the conditions for fixation, and the concentration of potassium in the soil were entirely different in the laboratory studies than they would be under natural conditions. The comparative fixation powers of the different soil types, and the comparison between effect of treatment on water-soluble potassium and exchangeable potassium are of much greater importance.

After consideration of Table 5, it is apparent that Fox gravelly loam was more active in the fixation of potassium than any of the other three soils. It would be unwise to attempt to differentiate between the fixation powers of Fox fine sandy loam and Fox coarse sand. They appear to be approximately equal in this respect. The fixation of potassium by Plainfield sand was in general lower than the fixation by the other three soils.

The addition of lime to the soils seemed to have an opposite effect on water-soluble and on exchangeable potassium. The fixation of potassium in the non-water-soluble form was somewhat greater in limed soils than in unlimed soils. On the other hand, the fixation of potassium in the non-exchangeable form was less in limed soils than in unlimed. It appears that in most cases, the addition of lime resulted in greater fixation of potassium in the non-water-soluble form, and less fixation in the non-exchangeable form. This is also evident in the treatment of data as shown in Table 6.

If this exchangeable potassium is available, as it apparently is, then the effect of lime as exhibited here would be very favourable in as much as it would help to prevent loss of potassium by leaching and yet remain in a form which can be used by the plant.

The apparent difference in the effect of addition of lime on water-soluble potassium and exchangeable potassium, in the samples under study, instigated a treatment of data which would make this difference more easily distinguishable. In soils such as those used for the production of tobacco, leaching is undoubtedly a serious problem. The water-soluble portion of the plant nutrients is, of course, quite subject to leaching, whereas the exchangeable portion while still available to the plant is not affected in this way to the same extent. For this reason an increase in the proportion of exchangeable potassium to water-soluble potassium should be desirable.

In determining what is designated as the exchangeable potassium, neutral normal ammonium acetate was used for extraction. Naturally, with an extractant of this kind, the water-soluble potassium would be removed along with the exchangeable. If the water-soluble potassium is subtracted from that determined by extraction with ammonium acetate, the remainder should give a fair conception of that which is exchangeable but not water-soluble. In the following treatment of data this portion will be referred to as "exchangeable only".

An attempt has been made to compare the effect of treatment on this "exchangeable only" portion. In order to do this, it was necessary to take into consideration the fact that the proportion of exchangeable to water-soluble potassium varies to a considerable extent in the original soils. The effect of this variation was avoided in the calculations by subtracting

the amount of fixation as non-exchangeable potassium from the amount of fixation as non-water-soluble potassium.

The effect of liming on this "exchangeable only" portion as compared with unlimed soils is shown in Table 6. The calculations were made from the fixation figures on treated soils, incubated for 7 days, as shown in Table 4.

TABLE 6.—THE EFFECT OF LIME TREATMENT ON THE "EXCHANGEABLE ONLY" POTASSIUM IN TREATED SAMPLES (POUNDS OF K PER ACRE)

Soil type	Unlimed	Limed
Fox coarse sand	186	209
Fox gravelly loam	189	231
Plainfield sand	52	188
Fox fine sandy loam	189	314

The results show that the amount of potassium contained as the "exchangeable only" portion in the unlimed soils was practically the same for the three types, Fox coarse sand, Fox gravelly loam, and Fox fine sandy loam, while the amount contained in this form by the Plainfield sand was considerably less.

In all cases the lime-treated soils showed a decided increase in this portion, over the soils which were not treated with lime. The Plainfield sand while remaining lower than the other three types was evidently affected to a considerable extent by the addition of lime.

Effect of Treatment as Shown by Checks

In considering the figures on the checks presented in Table 4, it is seen that fixation of water-soluble potassium apparently occurred in the Fox gravelly loam soil, and in the lime treated Fox coarse sand, but in no other instance. Exchangeable potassium was evidently fixed by all 4 soil types both by limed and unlimed soils. No apparent difference in fixation of potassium in a non-exchangeable form existed between the lime treated and untreated soils.

Evidently similar conditions imposed on the checks and on the potassium treated samples resulted in different effects. In the case of treated soils, liming apparently decreased the fixation of exchangeable potassium, whereas it did not seem to exert this influence on the checks.

No consistent effect of lime was noticeable in the water-soluble potassium in the checks, whereas it apparently increased the amount of fixation of water-soluble potassium in the treated samples.

Although these results may appear somewhat conflicting, it must be remembered that the conditions as to concentration of potassium in the checks and in the treated soils were vastly different. The high concentration of potassium caused by the addition of that element at the rate of 1,000 lb. per acre to the treated soils would quite conceivably account for the variation. There was, apparently, a difference in the effect of liming on the natural levels of potassium in the soil and that exerted on additions to the soil.

Fixation of Potassium at Varying Lengths of Incubation Period

Fixation of potassium as influenced by different lengths of incubation periods was studied. The results are shown in Table 7.

TABLE 7.—AMOUNT OF FIXATION OF POTASSIUM IN TREATED SOILS AT DIFFERENT LENGTHS OF INCUBATION PERIOD (POUNDS PER ACRE)

Soil type	7 days		14 days		28 days	
	Non-W-S.	Non-Ex.	Non-W-S.	Non-Ex.	Non-W-S.	Non-Ex.
Fox coarse sand	704	518	682	460	774	522
Fox gravelly loam	835	646	875	686	898	696
Plainfield sand	578	526	705	404	680	443
Fox fine sandy loam	721	532	730	470	764	452

In general the fixation of water-soluble potassium increased from the seventh day to the twenty-eighth day.

The fixation of potassium in a non-replaceable form was not as consistent. The fixation in this form by Fox gravelly loam increased until the twenty-eighth day. The fixation by Fox coarse sand showed no significant increase after the seventh day. The fixation as non-replaceable potassium by Plainfield sand and Fox fine sandy loam apparently decreased from the seventh day to the twenty-eighth day.

The fixation of potassium by Fox gravelly loam both as non-water-soluble and non-replaceable showed a consistent increase from 7 to 28 days, indicating that the fixation power of this type of soil was still active during this time. With the exception of this one type of soil, it would appear that in general the fixation of water-soluble potassium continues after the seventh day, but that there is no significant increase in the fixation of the replaceable potassium. The fixation of potassium in either form was not of any great magnitude after the seventh day.

The Change in pH of the Different Soils as a Result of Treatment and its Effect on the Fixation of Potassium

The change in pH of the soils as a result of the addition of lime shows no definite effect on the water-soluble potassium. The effect which it may have had on the replaceable potassium is problematical. Certainly the amount of potassium fixed in a non-exchangeable form was less in the limed soils than that fixed in the unlimed soils. Moreover, the effect is more marked in the acid soils which did undergo a change of pH as a result of the addition of lime. Whether the difference in fixation by the limed and unlimed soils is the result of the decreased acidity or of some other influence of the lime, is difficult to say. The fact that the change of pH was not particularly great in any case, coupled with the fact that the lime showed the same effect on fixation on an already alkaline soil as on the acid soils, would give the impression that some other influence was exerted by the lime. Probably a combination of factors was responsible for the greater difference in the acid soils.

SUMMARY

Exchangeable Potassium in the Principal Flue-Cured Tobacco Soil Types of Norfolk County

Plainfield sand, Fox gravelly loam, and Fox coarse sand were found to contain averages of 55 p.p.m., 47 p.p.m., and 36 p.p.m. respectively of exchangeable potassium. These levels are particularly low for crop pro-

duction. When considered from the standpoint of a heavy feeding crop such as tobacco, the lack of sufficiently high levels of potassium becomes even more serious.

Potassium Fixation Studies

The fixation studies were carried on under laboratory conditions on 4 flue-cured tobacco soil types.

1. A mechanical examination of the 4 soils revealed that Plainfield sand, Fox coarse sand, and Fox fine sandy loam were all similar in their contents of sand and total colloidal material. Fox gravelly loam was definitely higher in colloids and lower in sand than the other 3 types.

2. More potassium was fixed in a non-water-soluble form than in a non-exchangeable form.

3. Fixation of potassium in a non-water-soluble form was slightly greater in limed soils than in unlimed soils.

4. Fixation of potassium in a non-exchangeable form was less in limed soils than in unlimed soils.

5. Fox gravelly loam was definitely more active than the other 3 types in fixing potassium both as non-water-soluble and non-exchangeable. This was probably the result of the greater proportion of colloidal material contained by the Fox gravelly loam. In general, the fixation powers of Fox coarse sand and Fox fine sandy loam were nearly equal, with Plainfield sand being slightly less active in this respect, especially in the fixation of water-soluble potassium.

6. The "exchangeable only" portion of potassium in soils treated with potassium alone was practically equal for the 3 types, Fox coarse sand, Fox gravelly loam, and Fox fine sandy loam. This portion of potassium in Plainfield sand receiving the same treatment was decidedly lower. In all cases the lime treated soils which received added potassium showed a decided increase in this portion over soils which were not treated with lime. The Plainfield sand, however, remained lower in its content of "exchangeable only" potassium than the other three.

7. In check samples which received no application of potassium, the water-soluble potassium was fixed only by Fox gravelly loam and the lime treated Fox coarse sand. The exchangeable potassium was fixed by all 4 types of soil, and liming exhibited no apparent effect. Apparently the natural levels of potassium in the soil were affected differently by treatment than the added potassium.

8. With varying lengths of incubation periods, it was found that the fixation of potassium in a non-water-soluble form increased up until 28 days. Fixation of potassium in a non-exchangeable form increased after 7 days of treatment only in the Fox gravelly loam. In general the fixation of potassium was not of any great magnitude after the seventh day. It might be said, however, that the fixation power of the Fox gravelly loam was still active after this time.

9. The fixation of water-soluble potassium was evidently unaffected by a change in pH of the soils as a result of the addition of lime. In 2 soils which were made alkaline by the addition of lime, the effect of lime in decreasing the fixation of potassium in a non-exchangeable form appeared

to be greater. It is doubtful if the effect of lime on fixation was due entirely to a change of pH, as the same effect was noticed to a smaller extent in the alkaline Fox gravelly loam which underwent no change in pH.

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SOME OBSERVATIONS ON THE WORK OF THE MACDONALD COLLEGE SOIL FERTILITY COMMITTEE[1, 2]

W. A. DeLong[3]

The Macdonald College Soil Fertility Project is a co-operative undertaking participated in by the departments of Chemistry, Bacteriology, Agronomy and Physics, under the direction of the Macdonald College Soil Fertility Committee. Studies under this project have been carried on in the Eastern Townships of Quebec since 1931, and chemical, microbiological, and physical reports originating in the work of the project have been published from time to time. A list of the more important of these publications is given at the end of this paper. The primary aim of the present communication is to present an account of the various phases of activity from the standpoint of soil fertility.

Most of the experiments have been conducted in Compton County in the vicinity of the village of Sawyerville. The dominant geological formations in this region consist of Ordovician black and grey slates of the Trenton and Black River series. The general soil types of the Eastern Townships district have been reported upon by McKibbin and Pugsley (2). Some of the important characteristics of the surface soils of the experimental areas studied under the Soil Fertility Project are as follows:—

1. They contain 3 to 6% of organic carbon in the form of somewhat poorly decomposed organic matter which has a relatively high water-retaining capacity.

2. The nitrogen content is of the order of 0.2 to 0.35%, giving a C : N ratio of about 15.

3. They contain 0.5 to 1.0% calcium oxide, and the magnesium oxide content commonly exceeds that of calcium oxide.

4. The amount of phosphoric oxide present is of the order of 0.13 to 0.30%.

5. The potash content is about 1.5%.

6. In texture these soils are sandy loams to loams.

7. The reaction is strongly acid, pH 4.8 to 5.8; the Jones Lime requirement value is of the order of 2 to 5 tons of limestone per acre; the percentage base saturation is often less than 20, with an exchange capacity of 15 milliequivalents per 100 grams of air-dried soil. The application of liming materials in excess of the Jones Lime requirement value may not fully saturate these soils, and the degree of saturation so attained falls off rather rapidly.

8. Azotobacter seems to be absent from these soils and is not induced to grow in them by liming alone. Under laboratory conditions growth of this organism may be induced by addition of both phosphate and limestone.

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[1] Contribution from the Faculty of Agriculture of McGill University, Macdonald College, P.Q., Canada, with assistance from the Department of Agriculture of Quebec, Quebec. Macdonald College Journal Series No. 105.

[2] Presented before the Soils Group of the Canadian Society of Technical Agriculturists at Ottawa, June 27–30, 1938.

[3] Assistant Professor of Chemistry, Macdonald College; Chairman, Macdonald College Soil Fertility Committee.

McKibbin and Pugsley (2) mentioned three types of soil as occurring generally in Compton County: non-podsolized; podsolized (usually heavily); and, on the poorly drained areas, muck swamp. On practically all knolls, hill tops, and hillsides in this area they report the soil to be strongly leached. It is on soils of this leached type that most of the experimental work has been carried out.

The principal attack upon the problem of the improvement of the fertility of these soils has been centred about the use of soil amendments with a view to improving soil conditions for the multiplication and increase in activity of the more favourable soil organisms. It was thought that with the use of amendments and the improvement expected to result therefrom in the population and character of the microflora, the decomposition of the natural supply of rather inert and incompletely decomposed organic matter might be effected, resulting in an increase in the available plant food and better crop yields at an economical cost. In addition, a variety of fertilizer applications has been made, and cultural practices tried, with similar objects in view.

In 1931 and 1932 soil response to treatments applied was measured through the medium of laboratory tests only; since 1933, crop yields, and since 1935, the character of the flora, have also been used as criteria of response.

In 1931 and 1932 the treatments were: nil, ground limestone (12,000 pounds), nitrate of soda (200 pounds), acid phosphate (800 pounds), sulphate of potash (200 pounds), fallowing, and deep ploughing (10–12 inches) versus ploughing at the ordinary depth. Experiments were carried out on three farms. In 1931 oats were grown on two of the farms, corn on the third. In 1932 the crop at all three locations was swede turnips, and all the treatments except liming were repeated in this year. Measures of biological activity used as criteria of effect were, carbon dioxide production, numbers of micro-organisms,[4] and the nitrate-nitrogen content of the fresh soil. In each of the 2 years and on all 3 farms, the only treatment giving definite response in terms of carbon dioxide production and numbers of micro-organisms was ground limestone, both the carbon dioxide production and the numbers of micro-organisms being about doubled by liming. Measured in this way, the effect of liming was only slightly diminished in the second season. On the other hand, 2 consecutive annual applications of the fertilizer materials were without significant effect on biological activity. No treatment showed any significant effect on the nitrate-nitrogen content of the fresh soil samples, with the possible exception of deep ploughing, which appeared to depress nitrification. The samples from the different farms showed, however, considerable variation in nitrate content. This was ascribed to differences in soil texture, and, in the first season, to the nature of the crop grown. It was probably due mainly to the former of these factors, since much the same variations were found in each of the 2 seasons and the crop was uniform in the second season.

In 1932 additional experiments were started using caustic amendments, with the idea of still further accelerating the decomposition of the organic matter in these soils. The materials employed were sodium carbonate, sodium hydroxide, and quicklime, applied separately and in various com-

[4] Throughout this paper the term "numbers of micro-organisms" refers to bacteria plus actinomycetes.

binations and rates of application. It was found in that year that combinations of quicklime (5,000 pounds) with sodium hydroxide (400 pounds) or sodium carbonate (500 or 1,000 pounds) resulted in a 50% increase in carbon dioxide production and in numbers of micro-organisms over the values found for the untreated plots. As compared with an application of 6 tons of ground limestone, these caustic amendments increased the number of micro-organisms relatively more than they increased the carbon dioxide production. Observations were again made on these plots in 1933 and the results confirmed the findings of the preceding year.

In 1933 the most comprehensive series of experimental plots laid down during the course of this work was inaugurated. Treatments included, quicklime (3,000 pounds), ground limestone (6,000 pounds), sodium hydroxide (400 pounds), sodium carbonate (1,000 pounds), acid phosphate (500 pounds), muriate of potash (200 pounds), nitrate of soda (150 pounds), urea (100 pounds), and calcium cyanamide (150 pounds). The treatments were given singly or in combinations of the fertilizers with each other and with the amendments. Treatments were randomized within the experimental area and also duplicated. In 1934 the applications of nitrate of soda, urea and calcium cyanamide, but of no other materials, were repeated. Oats seeded to hay was the first crop. Yields were taken and analyzed statistically in the case of this and the 3 succeeding hay crops grown on these plots. The reliability of the yields in 1933 was somewhat vitiated by the lodging of the oat crop. Treatments producing significant increases in yield of the latter were phosphorus and phosphorus plus potassium among the fertilizers, sodium hydroxide, and sodium carbonate among the amendments. The yields produced by the latter were significantly greater than those from the quicklime, ground limestone or control plots. This effect of sodium compounds upon the oat crop has been repeatedly confirmed on the soils of this region. The mechanism of the effect, which has been previously reported for sodium compounds in the case of wheat in other soils (3), remains obscure. However, the field observations of the past 2 seasons indicate that the influence of sodium carbonate on the oat crop closely resembles that of fertilization with acid phosphate plus muriate of potash. This might be expected because of the known effects of alkaline carbonate solutions in bringing into solution organic forms of phosphorus and iron and aluminium phosphates, and of the sodium-ion in increasing the efficiency of a low supply of available potassium. Some ash analyses by Mr. H. L. Fletcher[5] of the grain and straw from sodium carbonate-treated versus control plots have indicated that this treatment increases the ash content, depresses the calcium and manganese, and perhaps increases the iron content of the straw. It may be noted here that it has recently been shown (1) that treatment of these soils with sodium carbonate brings iron into solution as the humate.

With further regard to the yield results of 1933 it may be added that the phosphorus plus potassium treatment produced a significant increase in the weight per measured bushel of the grain, while urea and calcium cyanamide caused a significant depression of this value. There were also indications that quicklime had a favourable effect on the filling of the grain as compared with ground limestone.

[5] Formerly assistant in the field and laboratory work of the Soil Fertility Project.

Laboratory studies on soil samples from these plots indicated that the application of either sodium carbonate or sodium hydroxide tended to increase the exchangeable sodium without appreciably altering the content of other exchangeable cations with the exception of hydrogen. This finding has been confirmed recently.

The records of the hay yields from these plots in 1934 were somewhat incomplete owing to the fact that spring applications of the amounts of sodium carbonate and sodium hydroxide used had killed the young clover and timothy plants. Subsequent experiments by Mr. Bird of the Agronomy Department indicated that the effect was largely of a physical nature, the application of these materials leading to the formation of a hard crust on the soil which the young seedlings were unable to penetrate. In the later work sodium carbonate has been applied in the autumn before seeding, under which conditions no ill effects upon the hay crop have been observed. Among the non-sodium treatments the following were found significantly to increase the yield of the first hay crop, namely:—

Phosphorus and potassium over no phosphorus and no potassium;

Phosphorus plus potassium over all plots not receiving this treatment;

All forms of nitrogen over no nitrogen (There was an application of nitrogen directly to this hay crop);

Calcium over no calcium and also over sodium.

On the second hay crop from this experimental area the following treatments gave significant increase in yield, namely:—

Phosphorus over no phosphorus;

Calcium over no calcium and also over sodium.

In the case of the third year hay crop the only treatment giving a significant increase in yield over the control plots was calcium.

The above finding with respect to the relative effects of calcium versus sodium compounds on the hay crop has since been repeatedly confirmed under conditions where the sodium treatment did not cause injury to the young seedling, that is, with fall application of sodium carbonate. In our experience sodium carbonate has not been found to have any significant effect in increasing hay yields on the soils of this district, notwithstanding the fact that it is equal or superior to ground limestone in stimulating the increase in the numbers of micro-organisms in the soil, the latter effect being apparent in both the first and second seasons after application.

A new series of plots was inaugurated in 1934 comprising the following treatments; sulphate of ammonia plus nitrate of soda (in chemically equivalent amounts and equal to 150 pounds of nitrate of soda), acid phosphate, muriate of potash, sodium carbonate, and ground limestone, the rates of application of these latter materials being the same as in 1933. The treatments mentioned were applied singly and in combination; they were randomized within the experimental areas, and the experiment was replicated on each of 4 farms. The experiment on one farm was dropped after the first year, and a second one eliminated the following year. As usual in these experiments, the first crop was oats seeded to hay. For the oat crop, nitrogen gave in this year (1934) a significant increase over no

nitrogen, and sodium carbonate a highly significant increase over no sodium. In the case of the clover crop on the 3 remaining farms, phosphorus gave a significant increase over no phosphorus, and limestone over no limestone and over sodium carbonate as well. For the succeeding timothy crop on 2 farms significant increases were obtained for limestone over no limestone and over sodium carbonate.

Laboratory experiments were conducted during 1934 to compare the effects of various carbonates in increasing the carbon dioxide output of and the numbers of micro-organisms in the soils of the district, and also their relative effects on bringing organic matter into solution. The results showed that magnesium carbonate was especially effective. As a consequence of this work an experiment was inaugurated in 1935 to compare the effect of different magnesium carriers on the yields of oats and of hay. The treatments were: ignited asbestos waste (8,000 pounds), the chrysotile fraction from asbestos waste (8,000 pounds), dolomite (8,000 pounds), "Linifrit[6]" (4,000 pounds), magnesium carbonate (8,000 pounds), Epsom salts (1,000 pounds), gypsum (700 pounds), ground limestone (8,000 pounds), and nil.

Statistical analysis of the yields of the oat crop obtained in this experiment with magnesium carriers showed that "Linifrit" just reached the point of significance in increase of yield over the nil plot, and that no other treatment reached this point. All the magnesium treatments had a deleterious effect on the young hay plants, and where they were applied a poor catch resulted; in fact, there is still very little vegetation on the plot to which magnesium carbonate was applied. For the first hay crop limestone gave a yield significantly greater than any other treatment except dolomite, while chrysotile and ignited asbestos waste gave significant increases over the nil plots. In the case of the second year hay, limestone was superior to all other treatments, and dolomite, chrysotile, and ignited asbestos waste again gave yields significantly higher than those from untreated plots.

As previously mentioned, beginning with the year 1935 estimates have been made by Mr. Bird of the Agronomy Department of the percentage contribution of the various useful grasses and legumes, and of weeds, to the yields of the hay plots on the various experimental areas. These analyses have shown that plots receiving calcium treatments have obtained and maintained particularly good stands of timothy. From these analyses it would further appear that, next to calcium, phosphorus is the most effective factor in securing a good stand of this grass on the soils of the district.

In the year 1935 additional sets of plots were established on 4 farms using amendments treatment only. The treatments were, nil, sodium carbonate (1,000 pounds), and limestone (6,000 pounds), alone and in combination, and triplicated at each location. For the 1936 oat crop from these plots significant increases in yield were obtained from limestone over no limestone, and from sodium carbonate over no sodium carbonate and over limestone. Similarly, the weight per measured bushel of the grain from the sodium carbonate plots was significantly greater than that of the grain from any other plots. The results for the hay crops from these

[6] "Linifrit" contains about 70% magnesium oxide, 20% calcium oxide; the residue is mainly silica.

areas agreed with those previously obtained in that limestone was found markedly superior to sodium carbonate in securing and maintaining a good stand and yield.

In 1937 another series of amendment and fertilizer plots similar to those established in 1934 was inaugurated. The treatments were nil, sodium carbonate (1,000 pounds), limestone (6,000 pounds), nitrate of soda (150 pounds), acid phosphate (500 pounds), muriate of potash (150 pounds), alone and in combination. This series was installed on 1 farm only, the treatments being randomized within the experimental area and duplicated. The results from the oat crop in that year, one of relatively heavy rainfall during the growing season, differed from those of previous years in that potassium was found to give a significant increase in yield, while no other treatment, not even sodium carbonate, did so. This result is ascribed to the fact that the crop on the potassium-treated plots matured earlier and suffered relatively less from lodging than plots without addition of this element. The effects of nitrogen in depressing the weight per measured bushel of the grain, and of phosphorus and of sodium in increasing this value, were again noted. In addition, potassium also gave an increase in weight per measured bushel of the grain in this season.

A summary of the treatments which have given significant increases in yield of oats and of hay crops as determined from the study of some 500 plots in the Sawyerville district is given in Table 1.

Table 1.—Treatments giving statistically significant increase in yields

Oats—		
1933.	One farm.	Sodium carbonate—Phosphorus—Phosphorus plus Potassium.
1934.	Four farms.	Sodium carbonate—Nitrogen.
1936.	Three farms.	Sodium carbonate—Limestone. (No fertilizers applied in this experiment.)
1937.	One farm.	Potassium.
Clover—		
1934.	One farm.	Limestone—Phosphorus—Phosphorus plus Potassium—Nitrogen.
1935.	Three farms.	Limestone—Phosphorus.
1935.	One farm.	Limestone. (No fertilizers used in this experiment.)
Timothy (First Year)—		
1935.	One farm.	Limestone—Phosphorus.
1936.	Three farms.	Limestone.
1937.	One farm.	Limestone. (No fertilizers used in this experiment.)
Timothy (Second Year)—		
1936.	One farm.	Limestone.

This summary indicates the marked benefits that the hay crops have derived from the application of limestone and of phosphorus to the soils of this region. In the case of the oat crop sodium carbonate has given outstanding results. The effects of this treatment are no doubt indirect, and, as already noted, may with some degree of probability be ascribed to the increased solubility of phosphorus and to an increased efficiency in the utilization of potassium. This interpretation of the results is supported by the significant effects obtained from applications of phosphorus plus potassium in 1933.

We have now discarded the use of sodium carbonate in these soil fertility experiments. The chief reason for eliminating this treatment is the fact that it seems quite unlikely that it will prove economically possible to employ sodium carbonate for this purpose in the near future, especially as the benefits obtained appear quite definitely to be confined to the grain crop under Eastern Township conditions. The project is being continued; further information is being sought regarding the optimum amount of limestone to apply, and on the effects of the usual and of some less common plant nutrients.

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69160—6

RENOVATION OF OLD MEADOWS WITHOUT RESEEDING[1]

S. A. Hilton[2] and C. D. T. Cameron[3]

In the spring of 1931 a number of field plots were established at the Dominion Experimental Farm, Nappan, Nova Scotia, for the purpose of studying the effects of various fertilizer formulae as top dressings on hay fields of low fertility. The results of this experiment, over a 7-year period, are reported in this paper.

OUTLINE AND PROCEDURE

The experiment was located on a medium clay loam area of low fertility. There is no record of any applications of manure or commercial fertilizer having been made to this area from the year 1914, until the start of this experiment. The field was ploughed and reseeded in 1923, with a nurse crop, and has been cut for hay each year since that date.

In 1931, there were located on this area 36 experimental plots 1/100 acre each in size; 14 fertilizer treatments were applied in duplicate, with 8 untreated plots left as checks.

The fertilizers were applied as broadcast top-dressings on the sod in the spring, at the following rates:—

250 lbs. nitrate of soda (N) per acre annually;

194 lbs. sulphate of ammonia (SA) per acre annually;

250 lbs. nitrochalk (NC) per acre annually;

500 lbs. 16% superphosphate (P) per acre in 1931, 1932 and 1936;

100 lbs. 50% muriate of potash (K) per acre in 1931, 1932 and 1936;

4,000 lbs. ground limestone (L) per acre in 1931 and 1936.

The treatments consisted of each of the above fertilizers applied alone, together with the following combinations: N-P, N-K, N-L, P-K, P-L, K-L, N-P-K, N-P-K-L.

The hay crop was harvested in July, the green weight recorded and 2-pound representative samples taken from each plot for dry matter determination.

In conjunction with the yield data the net value of the crop per acre, after deducting the cost of fertilizer was recorded. The prevailing market price for hay in November of each year was used as a basis for this study, together with the actual cost of the fertilizers used.

RESULTS

The data for each of the 7 years the experiment has been conducted are presented in Table 1.

A study of Table 1 would indicate that under the conditions of this experiment, little or no response, as measured by hay yields, was secured from nitrate of soda, nitrochalk or potash when applied alone, while limestone alone tended to depress the yield immediately following the applica-

[1] Presented before the Soils Group of the Canadian Society of Technical Agriculturists at Ottawa, Ontario June 27–30, 1938.

[2] Assistant Superintendent.

[3] Graduate Assistant.

tion. From an economical standpoint, it is interesting to note that the only treatments which have given a sufficient increase in yield to pay for the fertilizer used are those containing phosphorus.

TABLE 1.—HAY YIELDS AND NET VALUE OF CROP FOR 1931–1937

Treatment	Average yield of hay per acre (tons)								Value of crop per acre after deducting the cost of fertilizer. Average, 7 years
	Year							Average, 7 years	
	1931	1932	1933	1934	1935	1936	1937		
									$ c.
N	1.26	1.46	1.02	0.70	1.07	1.25	1.49	1.18	4.63
SA	1.23	2.19	1.50	0.85	1.27	1.59	1.77	1.49	8.70
NC	1.52	1.52	1.18	0.63	0.77	1.16	1.36	1.16	4.94
P	1.79	2.03	1.25	0.90	1.04	1.68	2.19	1.55	11.02
K	1.45	1.61	1.12	0.73	0.60	1.19	1.33	1.15	8.60
L	0.91	1.30	1.12	0.82	0.72	1.17	1.07	1.02	6.25
N-P	1.87	2.60	2.60	1.64	1.77	2.42	2.74	2.23	11.63
N-K	1.39	1.87	1.21	0.81	0.91	1.26	1.37	1.26	4.37
N-L	1.17	1.68	1.21	0.93	1.10	1.38	1.57	1.29	3.37
P-K	1.79	2.21	1.84	1.18	1.37	2.18	2.62	1.88	12.92
P-L	1.72	2.38	1.84	1.31	1.23	1.95	2.44	1.84	11.16
K-L	1.57	1.97	1.41	0.99	0.83	1.46	1.80	1.43	8.73
N-P-K	2.23	3.09	2.30	1.74	1.87	2.67	3.15	2.44	12.37
N-P-K-L	2.16	3.00	2.45	2.09	1.99	2.72	3.09	2.49	10.83
Check	1.26	1.47	1.14	0.71	0.72	1.21	1.32	1.12	9.24

STATISTICAL TREATMENT OF DATA

In view of the fact that the increases over the checks were very noticeable, it was thought that the analysis of variance method might be safely applied, although the experiment was not originally designed with this in view. The results of this analysis are given in Table 2 and the actual data from which the analysis was made are reported in Appendix Table 1.

TABLE 2.—ANALYSIS OF VARIANCE OF THE DRY MATTER YIELD FROM 15 FERTILIZER TREATMENTS

Sources of variance	D.F.	S.S.	M. sq. or variance	F	F. values	
					At 5% level	At 1% level
Treatments	14	14,972	1,069.43	39.00	1.79	2.26
Replicates	1	11	11.00	–	–	–
Years	6	8,219	1,369.83	49.96	2.19	2.99
Interaction—						
Treatment × years	84	1,819	21.65	–	–	–
Error	104	2,852	27.42	–	–	–
Total	209	27,873	–	–	–	–

Table 2 indicates that there is a highly significant difference between treatments, and also between the yields secured in the various years the experiment has been in progress. No significant difference was found,

however, between replicates or in the interaction of treatments and years, indicating that the differences between treatments may be expected regardless of the effect of the season on crop growth. As both dry and wet years were experienced during the period of this experiment, also high and low crop yields, this point is of major importance in recommending treatments for hay land.

TABLE 3.—THE MEAN YIELDS OF DRY MATTER OF THE 15 TREATMENTS AS AN AVERAGE OF THE 7 YEARS

Treatment	Average yield of dry matter, cwt. per acre	Increase over check	Remarks
N	20.6	2.5	
SA	26.0	7.9	Highly significant
NC	20.1	2.0	
P	27.1	9.0	Highly significant
K	19.9	1.8	
L	17.8	−0.3	
N-P	38.9	20.8	
N-K	22.0	3.9	Highly significant
N-L	22.9	4.8	Significant
P-K	32.9	14.8	Highly significant
P-L	32.1	14.0	Highly significant
K-L	25.0	6.9	Highly significant
N-P-K	42.6	24.5	Highly significant
N-P-K-L	43.6	25.5	Highly significant
Check	18.1		

NOTE.—Difference necessary for significance at 5% level=4.0; at 1% level=5.1.

Nine of the 14 treatments show significantly increased yields over the untreated areas. Potash and lime was the only combination not containing phosphorus that gave a significant increase. Lime alone shows a slight, although not significant, decrease when compared with the untreated areas. Sulphate of ammonia was the only source of nitrogen that increased the yields to the point of significance.

Comparisons of the effects of the various fertilizer combinations on the yields obtained are summarized in Table 4.

TABLE 4.—COMPARISON OF TREATMENTS ALONE AND IN COMBINATION

When applied alone					When combined		
Treatment	Average dry matter increase over check, cwt. per acre	Treatment	Average dry matter increase over check, cwt. per acre	Total increase	Treatment	Average dry matter increase over check, cwt. per acre	Possible difference due to combination
N	2.5	P	9.0	11.5	N-P	20.8	9.3
N	2.5	K	1.8	4.3	N-K	3.9	− 0.4
N	2.5	L	− 0.3	2.2	N-L	4.8	2.6
N	2.5	P-K	14.8	17.3	N-P-K	24.5	7.2
P	9.0	K	1.8	10.8	P-K	14.8	4.0
P	9.0	L	− 0.3	8.7	P-L	14.0	5.3
P	9.0	N-K	3.9	12.9	N-P-K	24.5	11.6
K	1.8	L	− 0.3	1.5	K-L	6.9	5.4
K	1.8	N-P	20.8	22.6	N-P-K	24.5	1.9
L	− 0.3	N-P-K	24.5	24.2	N-P-K-L	25.5	1.3
N-P	20.8	K-L	6.9	27.7	N-P-K-L	25.5	− 2.2
N-K	3.9	P-L	14.0	17.9	N-P-K-L	25.5	7.6
N-L	4.8	P-K	14.8	19.6	N-P-K-L	25.5	5.9

This analysis substantiates the results of the experiment as presented in Tables 1 and 3, wherein the greatest increase from any single element was secured from phosphorus, while nitrogen and phosphorus gave the greatest increase from the combination of any 2 single elements.

SOIL ANALYSES

A representative sample of the first 6 inches of soil was taken in September, 1937, and analysed through the courtesy of Prof. L. C. Harlow, Provincial Chemist, Agricultural College, Truro, Nova Scotia. In November, further sampling was done and analysed by the Thornton rapid test method at Nappan, then forwarded to the Dominion Chemist at Ottawa for further study, the results of which are not yet available. The results of the Truro and Nappan analyses are presented in Table 5.

TABLE 5.—RESULTS OF SOIL ANALYSES

Treatment	Truro analyses			Nappan analyses		
	Thornton		Morgan	Thornton		
	P_2O_5	pH	K	P_2O_5	pH	K
N	L+	5.6	V.L.	L+	6.1	L
S-A	M−	5.6	V.L.	L	6.0	L−M
N-C	L−M	5.6	L	L+	6.0	L
P	L−M	5.6	L+	L−	6.0	L−
K	M−	6.4	V.L.	L+	6.5	L
L	M−	6.6	V.L.	L+	6.7	V.L.
N-P	L−M	6.0	V.L.	L+	6.7	L
N-K	L+	6.4	V.L.	L+	6.6	L−
N-L	M−H	6.4	V.L.	L−M	6.6	V.L.
P-K	M	5.6	V.L.	L+	6.0	L−
P-L	M+	6.5	V.L.	L	6.4	L−
K-L	L	5.9	L	L	6.3	L−
N-P-K	M+	5.4	L	L	6.0	V.L.
N-P-K-L	H+	6.5	L	L−	6.5	L−
Check	L+	5.6	L	L−	6.0	L−

The soil analyses and yield data reported demonstrate that the soil used in this experiment is deficient in available phosphorus. Since tests would indicate that a large proportion of the soils of the Maritime Provinces are deficient in this element, the results of the experiment reported in this paper should have a definite application in crop improvement. It is interesting to note that the heavy annual application of sulphate of ammonia has not increased soil acidity according to the data presented in Table 5. The generally higher pH readings secured in the Nappan analyses may be partly due to the difference in time of year when the samples were taken. This explanation is indicated by the fact that a sample taken from the check plots in July showed a pH of 4.6, while September samples showed a reading of 5.6 and November 6.0. These differences suggest the necessity of interpreting soil analyses to the farmer in the light of a possible relationship between season and availability of plant food.

BOTANICAL SURVEY

Botanical surveys of the plots in this experiment were made by Mr. Herbert Groh of the Division of Botany, Ottawa, in 1934, 1935 and 1937. The following are extracts taken from Mr. Groh's report for 1937, together with a table (Table 6) prepared by him comparing the changes noted in vegetation since his first survey.

"Data from 1937 botanical surveys set down with those from earlier years are in general agreement, but with minor changes worthy of notice.

"Ground cover is not now rated so high as it was, except on the check plots and on the limed and nitrochalk plots, where in each case moss (not so abundant and not increasing on the other plots) constitutes part of the ground cover, though no bulk of the vegetation. From observation and from knowledge of the species listed it is clear that bulk of vegetation on the other treated plots much exceeded that on the checks, effecting less complete ground cover. The latest yields studied are better on almost all fertilized plots than on the checks. Timothy, an open sod type of grass, also contributes to this deficiency of ground cover on fertilized as compared with check plots, a situation usually having the opposite implication.

"Grasses as a whole, and timothy in particular, are better on fertilized than on check plots, but this is not true of brown top which stands poor conditions. Grass improvement has been greatest with the more complete fertilizer formulae, and poorest with lime. The rather minor place of Kentucky and Canadian Blue grasses in the stand is dropping still lower.

"Legumes, taken all together, show an increase over previous years with most treatments, but white clover by itself shows a slight decrease. Plots receiving either lime or superphosphate appear to have a little the advantage, and plots receiving nitrogen the reverse.

"Weeds are naturally least where grass is strongest, with the more complete fertilizers; and most on the checks (and limed plots).

"The excess of moss on checks and limed plots is probably chiefly a result of lighter cover of other vegetation; since lime along with a good fertilizer formula is not characterized by much moss.

"The acid tolerance of brown top is clearly indicated by the low rating under lime or nitrochalk, and by its decrease where lime is added to complete fertilizer.

"Ox-eye daisy is the weed most evidently reduced by fertilizing, while dandelion seems to be encouraged. As already pointed out, lime, except with other fertilizers, scarcely counts as a fertilizer."

SUMMARY

A series of plots were established at the Dominion Experimental Farm, Nappan, N.S., in the spring of 1931, on a hay field of low fertility. Fifteen fertilizer treatments applied to the sod were compared over a 7-year period on the basis of yield of dry matter and hay per acre, economy of treatment, and the effect of treatment on type of vegetation.

TABLE 6

Indicators	Period	Checks (8 plots)	All except checks (28 plots)	Receiving N. (16 plots)	Receiving lime or nitrochalk (12 plots)	Receiving super-phos. (12 plots)	Receiving mur. pot. (12 plots)	Receiving N-P-K & lime (2 plots)	Receiving N-P-K (2 plots)
Ground cover	1934–35	96.2	97.3	97.5	97.5	97.7	97.9	98.5	98.0
	1937	97.0	94.5	93.0	96.0	91.0	93.0	88.0	86.0
Grasses	1934–35	38.5	49.0	52.8	37.4	53.4	49.3	67.5	66.8
	1937	36.5	41.0	45.6	35.0	47.0	43.0	51.0	56.5
Legumes	1934–35	6.5	7.1	4.7	7.8	10.0	5.5	8.0	6.3
	1937	9.6	9.0	6.4	10.3	9.0	9.0	8.5	4.5
Weeds	1934–35	42.8	34.0	32.4	35.2	27.8	34.8	20.3	23.5
	1937	43.0	40.0	38.0	44.3	32.0	37.0	28.0	25.0
Moss	1934–35	5.1	3.2	2.5	4.1	1.4	2.5	0.3	0.3
	1937	6.5	3.3	1.5	5.6	1.0	2.3	0.0	0.0
Couch grass	1934–35	3.9	6.2	8.4	10.0	10.4	4.4	0.3	0.0
	1937	0.5	1.5	2.0	1.0	1.0	1.0	0.0	0.0
Brown top	1934–35	22.2	18.8	17.3	16.6	20.7	19.2	12.3	23.0
	1937	28.0	22.0	23.0	16.0	21.0	19.0	14.5	21.5
Timothy	1934–35	8.7	15.3	12.9	15.2	23.4	21.1	42.5	37.5
	1937	7.0	14.0	15.0	14.0	23.0	21.7	36.0	35.0
White clover	1934–35	6.0	5.3	2.7	6.3	7.5	5.8	5.0	3.0
	1937	4.5	4.8	2.8	5.6	6.3	5.2	4.5	2.5
Fall dandelion	1934–35	11.1	9.8	9.7	10.3	8.5	8.4	6.5	5.0
	1937	10.0	8.6	7.0	10.5	7.4	7.5	5.5	5.5
King devil	1934–35	14.9	9.9	11.8	10.9	5.7	9.0	2.5	4.8
	1937	11.0	7.4	10.5	9.0	2.6	5.0	0.5	0.5
Ox-eye daisy	1934–35	4.0	4.5	4.2	4.8	3.9	4.9	3.3	4.3
	1937	2.0	2.4	2.0	3.0	1.0	2.0	0.5	0.5
Dandelion	1934–35	5.1	6.0	6.1	5.5	6.9	6.8	7.0	7.8
	1937	4.7	9.0	10.0	9.0	12.0	12.0	15.0	15.0

It was found that lack of phosphorus was apparently the chief limiting factor in the economical production of hay on this area. All treatments containing phosphorus, alone or in combination with other elements, gave significant increases in yield when compared with untreated areas.

Significant increases were secured from nitrogen alone when applied in the form of sulphate of ammonia, but not when applied as nitrate of soda or nitrochalk.

Potassium, alone, or with nitrogen (as nitrate of soda), did not give a significant increase in crop yield, but when combined with phosphorus or calcium, significant increases were obtained.

Calcium (as ground limestone), alone, showed a tendency to reduce yields immediately after application. When combined with the various fertilizing elements, a slight but not significant response was secured in increased yields.

Soil analyses would indicate that the area is moderately acid and very deficient in plant food.

Botanical surveys were made and indicate that marked changes are occurring in the flora on the area under experimentation, such changes being governed by the treatment applied, complete fertilization giving the greatest change.

ACKNOWLEDGMENTS

Acknowledgment is due Mr. J. L. Forsyth, Assistant Superintendent at the Dominion Experimental Farm, Nappan, N.S., for guidance in the statistical studies and helpful suggestions in the preparation of this paper; to Mr. Herbert Groh, of the Division of Botany, Ottawa, for the botanical surveys; and to Prof. L. C. Harlow, Provincial Chemist for Nova Scotia, for his co-operation in supplying analytical data on the soils under experimentation.

APPENDIX TABLE 1.—YIELDS OF DRY MATTER—CWT. PER ACRE

Treatment	Year													
	1931		1932		1933		1934		1935		1936		1937	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
N	20	23	24	26	15	20	9	14	17	20	20	30	23	27
S-A	22	20	30	45	21	30	14	15	21	22	26	37	28	33
N-C	20	31	23	29	16	24	9	12	13	13	21	25	24	22
P	26	35	35	34	23	20	15	15	17	18	34	33	40	34
K	20	29	22	32	17	21	10	15	7	13	22	26	20	25
L	16	15	20	25	18	21	11	17	10	14	23	23	21	15
N-P	30	33	45	43	46	42	30	26	27	33	48	49	48	45
N-K	21	26	33	31	22	19	15	13	15	16	25	25	24	23
N-L	20	20	29	28	18	23	17	15	19	19	30	30	26	27
P-K	39	22	43	32	31	32	28	12	24	22	47	40	47	42
P-L	37	21	47	34	30	33	29	15	22	20	39	39	41	42
K-L	37	17	44	23	28	20	25	9	21	7	35	23	38	23
N-P-K	38	38	54	52	36	42	32	27	31	32	49	58	47	60
N-P-K-L	38	33	52	50	43	41	42	30	40	28	62	47	49	56
Check	19	20	22	26	16	20	10	11	11	12	20	25	18	24

INFLUENCE OF LIME IN CROP ROTATION WITH A NOTE ON THE OCCURRENCE OF BORON DEFICIENCY IN MANGELS

W. S. Blair[2] and J. S. Leefe[3]
Dominion Experimental Station, Kentville, N.S.

The necessity of maintaining an adequate supply of calcium and a favourable soil reaction for clover, grain and cultivated crops is not generally recognized in western Nova Scotia. An experiment to test the effect of a number of fertilizer materials alone and in combination with ground limestone was laid down in the early days of the Experimental Station at Kentville. A great deal of data has been accumulated since that time and this paper is a report and discussion of the results for the whole period 1914 to 1937, inclusive.

MATERIALS AND METHODS

Plan of Experiment

The plan of the experiment is shown in Figure 1. The area occupied is approximately 1.25 acres, the plots being 1/20 of an acre each. The land slopes moderately from southwest to northeast.

Fertilizer Treatments and Crops Grown

The experiment has been operated as a 3-year rotation, a hoed crop followed by grain and clover hay. The schedule of crops grown is given in Table 1.

Table 1.—Crops grown in fertilizer and ground limestone experiment

Year	Crop	Year	Crop	Year	Crop
1914	Potatoes	1922	Clover	1930	Wheat
1915	Oats	1923	Potatoes	1931	Clover
1916	Clover	1924	Oats	1932	Mangels
1917	Potatoes	1925	Clover	1933	Wheat
1918	Wheat	1926	Mangels	1934	Clover
1919	Clover	1927	Wheat	1935	Mangels
1920	Potatoes	1928	Clover	1936	Wheat
1921	Wheat	1929	Mangels	1937	Clover

Never limed	Plot 5	Plot 4	Plot 3	Plot 6	Plot 2	Plot 1
Limed	Plot 5	Plot 4	Plot 3	Plot 6	Plot 2	Plot 1
	Plot 1	Plot 6	Plot 2	Plot 3	Plot 4	Plot 5
Never limed	Plot 1	Plot 6	Plot 2	Plot 3	Plot 4	Plot 5

N

Figure 1. Plan of experiment.

[1] Presented before a meeting of the Soils Group, C.S.T.A., at Ottawa, Ontario, June 27–30, 1938.
[2] Superintendent and Horticulturist.
[3] Assistant in field crops.

The fertilizers and limestone were applied to the land before the hoed crop was planted. The schedule of fertilizers is given in Table 2.

TABLE 2.—FERTILIZERS APPLIED TO HOED CROPS, POUNDS PER ACRE

Fertilizer applied		Plots					
		1	2	3	4	5	6
Nitrate of soda, 15%	Before 1926	140.0	–	70.0	70.0	50.0	–
	Since 1926	420.0	–	210.0	210.0	150.0	–
Sulphate of ammonia, 20%	Before 1926	–	105.0	52.5	52.5	37.5	–
	Since 1926	–	315.0	157.5	157.5	112.5	–
Superphosphate, 16%	Before 1926	150.0	150.0	300.0	–	–	–
	Since 1926	450.0	450.0	900.0	–	–	–
Slag, 16%	Before 1926	150.0	150.0	–	300.0	–	–
	Since 1926	450.0	450.0	–	900.0	–	–
Bonemeal, 20%	Before 1926	–	–	–	–	240.0	–
	Since 1926	–	–	–	–	720.0	–
Muriate of potash, 50%	Before 1926	101.2	101.2	101.2	101.2	101.2	–
	Since 1926	202.4	202.4	202.4	202.4	202.4	–

NOTE.—In addition to the fertilizers shown in Table 2, ground limestone at the rate of 2 tons per acre was applied to the limed areas in 1914, 1917, 1920 and 1923. In addition, in 1917, a blanket application of manure, 15 tons per acre, was made to the whole area.

The average yearly yields of the two duplicate plots of each treatment are given in Appendix Table 1, which contains all the relevant data.

Methods of Analysis

The reduction of so large an amount of numerical data as has been accumulated in this experiment presents a considerable problem. The determination of the order of differences required for significance is difficult since the layout of the test does not lend itself to statistical analysis by any of the ordinary methods.

However, throughout this report an attempt will be made to evaluate the various treatments on a basis of the mean annual differences between them. A sample of the procedure followed will be found in Appendix Tables 2 and 3.

With the clover hay yields, where 8 years' observations are available, it is possible, besides evaluating the significance of mean differences between yields, to evaluate the significance of the regression coefficients of the mean annual differences on years and establish whether or not the differences between pairs of treatments are increasing or decreasing. The differences designated as significant in this paper are those having a calculated probability of occurrence in random samples of not more than 5%.

Some observational data have been accumulated during the period. These have been included under the various headings. A supplementary test on mangels with various trace elements was also carried out on the west end of the experimental area in 1935. The results of this test are of interest in view of the difficulty found in growing mangels on this area.

RESULTS

Potatoes

Reference to Table 1 shows that potatoes were grown only in the early years of the experiment. The average annual yields for the various treatments are given in Table 3.

TABLE 3.—AVERAGE ANNUAL YIELDS OF POTATOES, BUSHELS PER ACRE

Plot	Treatment	Limed	Not limed	Difference
		bush.	bush.	bush.
1	Nitrate of soda, superphosphate, slag and potash	197.8	181.5	16.3
2	Sulphate of ammonia, superphosphate, slag and potash	190.0	171.6	18.4
3	Nitrate and sulphate, superphosphate and potash	197.1	183.5	13.6
4	Nitrate and sulphate, slag and potash	201.8	183.2	18.6
5	Nitrate and sulphate, bonemeal and potash	198.0	175.5	22.5*
6	No fertilizer	163.1	139.3	23.8*
	Mean	191.3	172.4	18.9*

*Significant difference.

From Table 3 it appears that the mean difference due to lime is significant. The effect of lime on the individual treatments is fairly uniform, although it appears to be somewhat more effective where bonemeal or where no fertilizer is used.

Some attempt was made to evaluate the effect of the fertilizer treatments under limed and unlimed conditions, but the effects are so variable and the differences so small that it seems best to consider the nitrogen and phosphorus sources used about equally effective.

In spite of the evident stimulation of the potato yields due to the lime treatment, the limed areas were never considered suitable for growing this crop. The incidence of potato scab was so great in the limed areas as to make the crop unmarketable. Consequently, potatoes were not grown in the experiment after 1923, except for a few rows in each plot in 1932 when again the incidence of scab was found to be too high for satisfactory potato growing. This, in spite of the fact that no lime had been applied to the area since 1923.

Mangels

Mangels have been grown as the hoed crop in this area since 1926. This crop has not been altogether successful as the mangels always have suffered from a disease which has become progressively worse with each crop. Experiments to determine the nature and control of this trouble have been carried out and will be presented in the next section. The average annual yields of the various treatments are presented in Table 4.

TABLE 4.—AVERAGE ANNUAL YIELDS OF MANGELS, BUSHELS PER ACRE

Plot	Treatment	Limed	Not limed	Difference
		bush.	bush.	bush.
1	Nitrate of soda, superphosphate, slag and potash	483.6	360.6	123.0*
2	Sulphate of ammonia, superphosphate, slag and potash	304.1	227.1	77.0
3	Nitrate of soda, sulphate of ammonia, superphosphate and potash	386.3	284.5	101.8*
4	Nitrate and sulphate, slag and potash	411.0	338.6	72.4
5	Nitrate and sulphate, bonemeal and potash	347.6	130.9	216.7*
6	No fertilizer	50.7	0.0	50.7
	Mean	330.5	223.6	106.8*

*Significant difference.

Table 4 shows that in its average effect lime has increased the yields of mangels by over 100 bushels per acre per year. The effect of the lime has been outstanding only in the cases of treatments 1, 3 and 5. The lime in treatment 6 has served to keep this plot in production, although the yield in this case has fallen from 100 bushels per acre in 1926 to 10 bushels per acre in 1935.

In order to show the possible effects of the individual fertilizer treatments some of the data from Table 4 are presented in a different way in Table 5.

TABLE 5.—AVERAGE ANNUAL DIFFERENCES OF MANGELS, BUSHELS PER ACRE

Difference between	With lime	Without lime
	bush.	bush.
Nitrate of soda (1) and sulphate of ammonia (2)	191.2	133.6
Slag (4) and superphosphate (3)	28.4	54.4
Superphosphate (3) and bonemeal (5)	38.7	153.6
Slag (4) and bonemeal (5)	63.4	207.7

NOTE.—Figures in parentheses refer to plot numbers in Table 4.

Great care should probably be exercised in ascribing statistical significance to results based on as few observations as those in Table 5; however, it would seem that nitrate has given much better results with mangels than sulphate of ammonia, whether or not the land was limed. Slag and superphosphate have been superior to bonemeal only when the land was not limed.

Disease Affecting Mangels

The disease affecting the mangels mentioned at the beginning of the previous section was studied and reported on by the Officer-in-Charge of the Field Laboratory of Plant Pathology stationed at the Experimental Station at Kentville.

The disease was identified in 1929 as *Phoma betae* (Oud.) Frank. The disease first appears as a seedling blight. Later in the season it shows itself as wart-like protuberances on the mid ribs of the young unfolding leaves. Finally, the crown of the plant is affected and turns black. This characteristic gives rise to the name heart rot or crown rot for the disease. In severe cases the entire foliage is killed. This trouble has been present in the mangels on this soil since they were first grown and has become worse each season.

The seedling stage of the disease does not appear to be definitely associated with the lime treatments, but the later stage always is worse on the limed areas. In 1929 the pathologist reported 56% of the plants affected in midsummer on the unlimed area as against 95% on the limed area. An interesting point in this connection is that while the infestation of disease was generally greater on the limed area, no mangels have ever grown on the unfertilized unlimed plot, but it always has been possible to produce a few plants on the unfertilized limed plot. This point was mentioned in connection with Table 4 in the previous section.

Brandenburg in 1931 first showed that heart rot, usually thought to be caused by parasites like *Phoma betae*, was a physiological trouble in which the associated parasite was connected only in a secondary way. He was able to demonstrate quite clearly that the physiological trouble was due to a deficiency of boron in the growth medium. Since that time it has become a standard practice in Europe to control this disease with applications of 15 to 25 pounds of borax per acre, the rate depending on the acidity of the soil; the more acid the soil the less boron is required.

In 1935 it was decided to test a number of trace elements, including boron, in their effect on the disease occurring in this experiment.

The ranges shown in Figure 1 extend a considerable distance beyond the fertilizer treatments at the western end of the field. This extension was laid out in test plots with the trace elements. The lime treatment at this end had always been the same as on the experimental area and it had always been given a complete fertilizer at the time of seeding the hoed crop. When the trace element test was laid out the area was given the same fertilizer treatment as Plot 1 in the regular experiment.

Table 6 gives the schedule of trace element treatments together with the data on heart rot infestation and yields for the year 1935. Plots 1 and 6 from the regular experimental area are included for comparison.

TABLE 6.—TREATMENTS IN POUNDS PER ACRE, PER CENT INFESTATION OF HEART ROT AT HARVEST AND YIELDS IN BUSHELS PER ACRE, 1935

Plot	Treatment, pounds per acre	Limed		Not limed	
		Yield	Heart rot	Yield	Heart rot
		bush.	%	bush.	%
1	See Table 4	265.4	89.0	185.1	81.0
6	No fertilizer	10.0	No record	0.0	No record
7	Magnesium sulphate, 120	280.7	85.0	297.6	73.0
8	Sodium borate, 10	926.8	2.0	409.0	0.0
9	Manganese sulphate, 50	256.5	91.0	292.8	61.0
10	Copper sulphate, 15	256.5	89.0	200.8	77.0
11	Zinc sulphate, 15	263.8	86.0	116.1	62.0
12	Manure, 30,000	288.0	85.0	295.2	58.0

Table 6 shows quite clearly that, even with the small amount of boron applied, the crown rot has been almost entirely eliminated. Furthermore, while the disease is usually more severe in the limed than the unlimed areas, when the boron requirement of the limed areas is satisfied, the lime is of value in stimulating the yield of the mangels.

Grains

Records of 6 crops of wheat and 2 crops of oats are available. The average annual yields of wheat for the various treatments are given in Table 7.

TABLE 7.—AVERAGE ANNUAL YIELDS OF WHEAT, BUSHELS PER ACRE

Plot	Treatment	Limed	Not limed	Difference
		bush.	bush.	bush.
1	Nitrate of soda, superphosphate, slag and potash	19.05	13.83	5.22*
2	Sulphate of ammonia, superphosphate, slag and potash	19.68	11.90	7.78*
3	Nitrate and sulphate, superphosphate and potash	19.18	11.95	7.23*
4	Nitrate and sulphate, slag and potash	21.55	13.05	8.50*
5	Nitrate and sulphate, bonemeal and potash	18.95	13.27	5.68*
6	No fertilizer	14.55	8.80	5.75*
	Mean	18.83	12.13	6.70*

*Significant differences.

Table 7 shows that the application of lime has increased the yield of wheat by an average of nearly 7 bushels per acre per year and that this increase has been fairly consistent throughout all the fertilizer treatments. Further comparisons between the yields of the various fertilizer treatments are presented in Table 8.

TABLE 8.—AVERAGE ANNUAL DIFFERENCES OF WHEAT, BUSHELS PER ACRE

Difference between	With lime	Without lime
	bush.	bush.
Nitrate of soda (1) and sulphate of ammonia (2)	−0.63	1.93*
Slag (4) and superphosphate (3)	2.37*	1.10
Superphosphate (3) and bonemeal (5)	0.23	−1.32*
Slag (4) and bonemeal (5)	2.60*	−0.22

*Significant values.

NOTE.—Numbers in parentheses refer to the treatments listed under these numbers in Table 4.

Table 8 is given to indicate possible sources of interaction between the fertilizer treatments and the lime. It shows that where lime is used sulphate of ammonia has been equal to nitrate of soda as a nitrogen source,

but where no lime was used nitrate of soda is significantly better than sulphate of ammonia. It also shows that where lime is used slag has been superior to superphosphate, but where no lime is used they are not significantly different. Without lime, bonemeal has given higher yields than superphosphate, while with lime these two are equal. Slag has been superior to bonemeal only when lime is used. The differences between no fertilizer and the various treatments are not shown in Table 8, but they may be calculated from Table 7. In all cases the results with fertilizer are definitely superior to those with no fertilizer.

For two years oats were grown as the grain crop in this experiment. The results are in line with those given for wheat although with so few results it is difficult to make adequate comparison. The average yield of oats from the limed area for the 2-year period is 38.2 bushels per acre, and for the unlimed area 30.1 bushels per acre.

Clover Hay

Clover hay has been grown as the third crop in the rotation in this experiment since the test was begun in 1914, therefore 8 years' records of clover hay yields are available. The average annual yields per acre are presented in Table 9.

TABLE 9.—AVERAGE ANNUAL YIELD OF CLOVER HAY, TONS PER ACRE

Plot	Treatment	Limed	Not limed	Difference
		tons	tons	tons
1	Nitrate of soda, superphosphate, slag and potash	1.787	0.921	0.866*
2	Sulphate of ammonia, superphosphate and potash, slag	1.556	0.595	0.961*
3	Nitrate of soda, sulphate, superphosphate and potash	1.606	0.609	0.997*
4	Nitrate and sulphate, slag and potash	1.785	0.887	0.898*
5	Nitrate and sulphate, bonemeal and potash	1.803	0.633	1.170*
6	No fertilizer	0.984	0.534	0.450*
	Mean	1.586	0.696	0.890*

*Significant differences.

Table 9 shows that in every case lime has significantly increased the clover yield. The average annual increase is nearly 1 ton per acre. The figures in Table 9 are reported as clover hay, but it should be kept in mind that the proportion of clover in the hay is always much higher on the limed than the unlimed plots and in recent years very little but weeds have grown on the unlimed plots 2 and 6. Clover stands have been very thin on the unlimed sections of plots 3 and 5. Considerable clover will still grow on the unlimed section of plot 4 and to a somewhat less extent on plot 1. Data to show the differences between the various fertilizer treatments are given in Table 10.

TABLE 10.—AVERAGE ANNUAL DIFFERENCES AND AVERAGE YEARLY RATES OF INCREASE IN THE DIFFERENCES, TONS PER ACRE OF CLOVER HAY

Differences between	With lime		Without lime	
	Average annual differences	Rates of increase in differences	Average annual differences	Rates of increase in differences
	tons	tons	tons	tons
Nitrate of soda (1) and sulphate of ammonia (2)	0.231*	0.063*	0.326*	0.123*
Slag (4) and superphosphate (3)	0.179	0.055*	0.278*	0.117*
Slag (4) and bonemeal (5)	−0.018	–	0.253	0.093
Superphosphate (3) and bonemeal (5)	−0.197	−0.097*	−0.024	–

*Significant values.

NOTE.—Figures in parentheses refer to plot treatments in Table 9.

Table 10 shows that in its average effect over the 8-rotation period nitrate of soda has given significantly greater yields of clover hay than sulphate of ammonia. This is true of the limed as well as the unlimed areas. However, this does not completely reflect what has been happening. The figures for rates of increase in the differences, which are the linear regression coefficients of annual yield difference on years, show that where lime has been applied the sulphate of ammonia treatment has been holding its own with nitrate of soda. This is deduced from the very low rate at which the difference between nitrate and sulphate is increasing, i.e., 0.063 tons per acre per year. Where no lime has been used sulphate of ammonia has definitely been losing ground in relation to nitrate of soda. The difference in yield between the two is increasing at the statistically significant rate of 0.123 tons per acre per year.

Similarly, slag has given better yields than superphosphate and is continuing to increase its lead although only half as fast on the limed as on the unlimed areas. Slag has not proved significantly superior to bonemeal nor bonemeal superior to superphosphate, although bonemeal appears to be gaining somewhat where lime has been used.

Soil Data

In July, 1937, shortly after cutting the hay on the plots, determinations of various mineral elements in the soil were made by means of two of the so-called short test methods. The results of these tests are presented in Table 11.

While it is realized that tests of the kind reported in Table 11 do not give an absolute index of the available elements present it is thought that the results given here reflect to some extent the treatment received by this soil. The pH is on an average one point higher where lime has been used. Potash shows a definite and phosphorus a slight tendency to be lower where lime is used. The association of low lime and high aluminium is quite evident from these tests.

Table 11.—Results of short tests* for mineral elements

Plot	pH		Phosphorus		Potassium		Calcium		Magnesium		Aluminium		Iron	
	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime
1	6.4	5.2	High	Medium	V. low	Medium	High	Low	Low	Low	Medium	V. high	Low	Low
2	6·2	5·0	Medium	High	Low	Medium	High	Low	Low	Low	Medium	V. high	Low	Low
3	6·0	5·0	High	High	V. low	Medium	High	Medium	Low	Low	Medium	V. high	Low	Medium
4	6.4	5.2	High	High	Low	Low	V. high	Medium	Medium	Low	Medium	V. high	Low	Low
5	6·2	5·4	Medium	High	High	V. high	V. high	Low	Medium	Low	Medium	V. high	Low	Low
6	6.4	4.8	Medium	Medium	V. low	Low	High	Low	Low	Low	Medium	V. high	Low	Low

*Phosphorus and pH by the "Thornton Rapid Testing System", other elements by the M. F. Morgan "Universal Soil-Testing System".

Mention must also be made in this section of the effect of the lime treatment on the physical condition of the soil. The section on clover hay shows that from 2 to 3 times the amount has been produced on the limed areas during the period from 1914 to 1937. There is no question that the mass of clover roots ploughed under in 8 rotations has improved the tilth, texture, and aeration of the soil. It has already been stated above that clover only grows satisfactorily on this soil where lime has been used.

DISCUSSION

Throughout this experiment the outstanding feature of the results has been the increase in the yields of all the crops due to the applications of lime in the early days of the experiment. The fact that applications of limestone were discontinued in 1923 does not appear to have caused any diminishing of this effect, although there is evidence of a general falling-off of yield with years on both the limed and unlimed sections with the mangel and wheat crops (see Appendix Table 1).

There is fairly conclusive evidence with mangels that the reduction in yield with years is due to a deficiency in the element boron. It seems reasonable to suppose that this deficiency would become more serious with each successive crop. In the light of discoveries in recent years of boron deficiencies in many agricultural crops, including cereals, it is conceivable that the falling-off of wheat yields in this experiment may also be due to this same cause.

The effect of lime in improving the soil appears to be due to two factors, *viz.*, counteracting soil acidity and stimulation of clover production, which in turn tends to improve the soil. The improvement in the soil from the clover appears to some extent as a bettered physical condition, while the addition of nitrogen fixed in the clover roots is no doubt an important factor in determining the increased fertility of the limed soil; which factor is of greatest importance would not be an easy matter to determine.

Not all the crops show the same stimulation due to the lime. Clover comes first, the increase in yield due to lime being over 100%, wheat is next, showing a difference in yield of some 50%, mangels are next with a slightly lower increase, while potatoes show a much smaller, though significant increase in yield due to lime. With potatoes, liming the land produced such an increase in scab that the larger part of each crop was unmarketable; it cannot, therefore, be said that liming land for potatoes is to be recommended.

The above remarks refer to the average effect of lime over a series of fertilizer treatments. The interaction effects of lime with various fertilizers, while they are perhaps of greater interest, are not so easy to determine. The data leave no doubt that in this experiment nitrate of soda is a superior source of nitrogen to sulphate of ammonia for mangels and for clover hay. This is true whether or not the land was limed, although on the limed areas the difference between the two nitrogen sources is not so great as on the unlimed areas.

Apart from this, however, on the unlimed areas, the continued use of sulphate of ammonia as against nitrate of soda is causing a progressively increasing difference in yield of clover hay in favour of nitrate of soda.

On the limed areas this is not the case, as here the difference between nitrate of soda and sulphate of ammonia has remained more nearly constant. From this it would seem that provided the land is limed adequately sulphate of ammonia would be a satisfactory source of nitrogen in a rotation, including clover, although nitrate of soda would undoubtedly be better. In any case, the effect of lime is more important than the source of nitrogen. With wheat, sulphate of ammonia appears to be equal to nitrate of soda on the limed land, but is definitely inferior where no lime was used.

The effects of the three sources of phosphorus used are not easy to explain. For clover, slag has proved superior to superphosphate whether or not the land was limed, though the difference is greater on the unlimed soil. Bonemeal, particularly on the limed soil, has proved to be as good as slag for the clover crop and there is some evidence that it has been superior to superphosphate in this respect. With wheat the slag shows superiority over superphosphate on the limed area and to a lesser extent on the unlimed area, while slag is superior to bonemeal on the limed area only. Bonemeal is superior to superphosphate but only on the unlimed soil. This is a direct reversal of the effect of these phosphorus sources on clover.

With mangels slag and superphosphate have given nearly equal results and both have proved superior to bonemeal, but only so on the unlimed land.

In view of the outstanding effects obtained from lime it might be expected that these phosphorus sources would be of value in the order of their ability to substitute for limestone, in which case on unlimed soils slag should be superior to superphosphate or bonemeal. However, this has only been the case with clover. The small amount of slowly available nitrogen supplied by bonemeal might be thought at first to be responsible for any superiority attributed to bonemeal on the second and third crop of the rotation. However, if this were so bonemeal should be superior to both slag and superphosphate. This is certainly not the case. Except in the two cases mentioned bonemeal has not been as useful a source of phosphorus as either slag or superphosphate, and while the differences between slag and superphosphate are interesting they are probably not of sufficient magnitude to make the choice of one or the other a question of great moment.

The question of boron deficiency in the soil in this experiment has already been discussed in a general way. The benefit to mangels obtained from a small application of borax is of great interest. Not only was the heart rot in the mangels almost entirely eliminated, but the yields were much larger. It is of particular interest that the application of boron greatly increased the beneficial effect of liming on this crop.

The results of the short soil tests probably give an approximate indication of the fertility of the soil in the experimental area. The very high aluminium on the unlimed areas is of noteworthy interest, and possibly accounts to some extent for the lower fertility of the unlimed areas. The fact that both phosphorus and potash show somewhat higher values on the unlimed areas in these short tests is possibly due to lower utilization of these materials by the clover on the unlimed soil. Some factor, such as

the high soluble aluminium, might be responsible for interfering with the uptake of phosphorus and potash by the crops on the unlimed soils, while not interfering with the removal of these materials by the extracting liquid used in the soil test. Effects of the kind found here would indicate that soil analysis should be interpreted with extreme care and as much as possible in the light of the responses of the plants to the soil in question.

SUMMARY

1. Under the conditions of this experiment applications of limestone in the early years have been the greatest single factor influencing the yields of all the crops.

2. The practice of liming the soil for potatoes cannot be recommended due to the great increase in potato scab produced by this treatment.

3. The source of nitrogen is of some importance with the mangel and clover crops, where nitrate of soda is superior to sulphate of ammonia. For grain, on the limed soil, and for potatoes, these two sources of nitrogen are about equal.

4. The effects of the three phosphorus sources used are somewhat variable but, generally speaking, bonemeal has not been so satisfactory as slag or superphosphate. Differences between slag and superphosphate are not sufficiently large to be of practical interest.

5. The soil in the experiment is definitely deficient in boron for the mangel crop and possibly so for wheat.

ACKNOWLEDGMENT

This experiment was planned by the Division of Chemistry, Central Experimental Farm, Ottawa. Officials of that Division co-operated closely throughout the experiment with the Superintendent of this Station.

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APPENDIX—TABLE 1

Year	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6	
	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime
	Potatoes, bushels per acre											
1914	85.8	73.5	86.3	69.6	90.4	83.7	92.4	84.8	78.6	69.1	67.5	55.8
1917	326.0	291.3	321.0	295.7	326.0	294.5	326.0	292.0	335.1	283.0	313.4	251.8
1920	195.5	216.5	198.0	199.3	202.5	205.6	207.6	203.3	200.5	184.8	150.0	154.1
1923	183.9	144.6	154.8	121.9	169.6	150.3	181.3	152.8	177.9	165.2	121.6	95.8
	Mangels, bushels per acre											
1926	570.0	373.2	340.8	201.4	445.0	251.8	461.0	417.8	421.2	117.2	101.2	Nil
1929	446.2	462.8	238.2	251.6	331.8	295.8	310.6	327.8	288.2	170.2	64.4	Nil
1932	632.9	421.4	411.2	336.6	513.5	391.3	620.4	455.4	485.8	153.1	27.1	Nil
1935	265.4	185.1	226.1	118.6	254.7	199.0	251.9	153.5	195.3	83.3	10.0	Nil
	Oats, bushels per acre											
1915	37.9	32.6	38.5	29.1	36.9	31.1	40.4	31.1	38.2	33.6	32.7	30.4
	Wheat, bushels per acre											
1918	28.8	23.5	29.0	23.5	31.1	23.0	32.5	24.1	29.6	24.5	29.8	19.5
1921	15.7	11.0	15.3	8.0	14.1	8.7	16.0	10.3	15.6	10.8	12.1	8.8
	Oats, bushels per acre											
1924	41.0	33.1	40.1	26.1	37.2	26.6	39.8	28.6	42.1	32.1	33.5	26.8
	Wheat, bushels per acre											
1927	25.8	17.5	29.3	17.2	27.6	17.3	28.0	17.8	22.6	17.8	19.5	11.1
1930	13.2	9.2	14.4	8.5	12.9	7.1	16.5	9.0	12.8	7.2	6.8	3.7
1933	15.5	13.6	17.5	9.2	17.3	10.7	21.1	9.2	20.8	13.1	10.9	5.2
1936	15.3	8.2	12.6	5.0	12.1	4.9	15.2	7.9	12.3	6.2	8.3	4.5
	Clover Hay, tons per acre											
1916	0.885	0.345	0.640	0.335	0.655	0.280	0.890	0.365	0.665	0.340	0.555	0.360
1919	2.460	1.535	2.410	1.540	2.395	1.490	2.535	1.700	2.320	1.330	2.045	1.320
1922	1.455	0.435	1.450	0.270	1.585	0.490	1.800	0.355	1.500	0.455	1.050	0.330
1925	2.215	1.175	2.040	0.855	2.280	0.885	2.105	1.010	2.660	1.115	1.430	1.010
1928	1.920	0.815	1.765	0.580	1.780	0.480	2.040	0.755	1.895	0.550	0.975	0.430
1931	1.680	0.825	1.550	0.585	1.595	0.540	1.680	0.895	1.680	0.490	0.705	0.415
1934	1.035	1.030	0.675	0.395	0.600	0.340	0.900	0.800	0.805	0.460	0.250	0.235
1937	2.650	1.211	1.920	0.205	1.960	0.370	2.330	1.220	2.895	0.320	0.865	0.175

APPENDIX—TABLE 2.—SAMPLE OF METHOD FOR DETERMINING SIGNIFICANCE OF DIFFERENCES BETWEEN LIME AND NO LIME

Annual differences between lime and no lime for each fertilizer treatment are written down as follows:—
(Mangel yields in Appendix, Table 1)

Year	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
1926	196.8	139.4	193.2	43.2	304.0	101.2
1929	3.4	−13.4	36.0	−17.2	118.0	64.4
1932	211.5	74.6	122.2	165.0	332.7	27 1
1935	80.3	107.5	55.7	98.4	112.0	10.0
Total	492.0	308.1	407.1	289.4	866.7	202.7
Mean	123.0	77.0	101.8	72.4	216.7	50.7
$S(X)^2$	90,633.86	36,733.33	56,657.57	39,069.64	229,573.29	15,223.21
$(SX)^2$	242,064.00	94,925.61	165,730.41	83,752.36	751,168.89	41,087.29
$\frac{(Sx)^2}{4}$	60,516.00	23,731.40	41,432.60	20,938.09	187,792.22	10,271.82

Total $S(X)^2 - \frac{(Sx)^2}{4} = 123{,}208.77$

$S^2 = 123{,}208.77/18 = 6844.93$
$S = 82.73$

$N = 4$ therefore $\sqrt{\frac{1}{N}} = .5$ so that the standard error of the mean annual difference between lime and no lime for any fertilizer treatment is $.5 \times 82.73 = 41.37$

*t for the various treatments is as follows:—

Plot 1=2.97, plot 2=1.86, plot 3=2.46, plot 4=1.75, plot 5=5.23, and plot 6=1.23. For 18 degrees of freedom the value of t at the 5% point is 2.101.

*For tables of t see Fisher, R. A., Statistical Methods for Research Workers, Oliver & Boyd.

APPENDIX—TABLE 3.—SAMPLE METHOD OF DETERMINING SIGNIFICANCE OF DIFFERENCES AND REGRESSION COEFFICIENTS

Annual differences between two fertilizer treatments under limed or unlimed conditions are written down as follows:—(See Clover yields in Appendix, Table 1)

Difference between Nitrate of Soda and Sulphate of Ammonia—No lime

Plot 1 and Plot 2 Year	Difference
1916	0.010
1919	−0.005
1922	0.165
1925	0.320
1928	0.235
1931	0.240
1934	0.635
1937	1.006
Total	2.606
Mean	0.3258
$S(x)^2$	1.6578
$(Sx)^2$	6.7912
$(Sx)^2/8$	0.8489
$S(x)^2 - \frac{(Sx)^2}{8}$	0.8089
*t =	$\sqrt{\frac{56}{0.8089}}$
=	2.71

x = annual difference, y = years
b = regression coefficient of x on y

$S(y-\bar{y})^2 = 42$
$S(x-\bar{x})^2 = 0.8089$
$Sx(y-\bar{y})^2 = 5.176$
$b = 0.1232$
$b^2 = 0.015178$
$b^2S(y-\bar{y})^2 = 0.6375$
$S(x-\bar{X})^2 = 0.8089 - 0.6375 = 0.1714$
$S^2 = 0.1714/6 = 0.0285$
$S^2/S(y-\bar{y})^2 = 0.000861$
Standard error of $b = \sqrt{0.000861} = 0.026$
$*t = \frac{0.1232}{0.026} = 4.738$

*t at the 5% point for 6 degrees of freedom is 2.477 and for 7 degrees is 2.365.